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ABSTRACT

The major purpose of a study was to identify the knowledge, skill, and cognitive process differences between expert and novice technicians on technical troubleshooting tasks. Identification of these differences was conducted through two investigations. Investigation 1 sought to describe differences in the declarative and procedural knowledge bases that expert and novice troubleshooters bring to a problem situation. This phase involved the development and administration of dependent measures to quantify the differences between the two groups. Investigation 2 sought to identify the differences in the troubleshooting performance of experts and novices. Two groups of subjects were selected: a novice group of five service technicians enrolled in a training course at the Onan Corporation in Minnesota and an expert group of five manufacturing technicians who troubleshoot failed generators at this same corporation. Subjects were presented with two generator sets that had selected faults installed in them. Each subject was asked to find the fault using any of the tools and materials that were available. In addition, the subjects were asked to "think aloud" so their verbalizations could be recorded for later analysis. Very definite differences were found in declarative knowledge, procedural knowledge, and directly and indirectly observable troubleshooting performance. The primary difference was that experts were able to select better information and generate better hypotheses, that is, in the types of information acquired, the types of procedural tests performed, and the types of hypotheses generated. (Appendixes, which comprise two-thirds of the document, include the instruments and extensive subject protocols.) (YLB)

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TRAINING AND DEVELOPMENT RESEARCH CENTER

Project Number Twenty

KNOWLEDGE AND SKILL DIFFERENCES BETWEEN EXPERT AND NOVICE SERVICE TECHNICIANS ON TECHNICAL TROUBLESHOOTING TASKS

Scott Duncan Johnson
July 1987

university of minnesota
DEPARTMENT OF VOCATIONAL AND TECHNICAL EDUCATION • ST. PAUL, MINNESOTA

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DEDICATION

My father, Vernon F. Johnson is an expert problem solver. The many thousands of hours we spent together building and repairing have allowed me to assimilate his unique ability to visualize, plan, and create. These skills seem foundational to the development of expert problem solving skills. A good problem solver must be able to visualize the system or device model that describes its operation. Without the development of an accurate mental model for technical systems and devices, a problem solver cannot make logical decisions on how to proceed through the problem. However, by using mental models, a good problem solver can plan ahead and make intelligent and logical decisions. The ability to create is a creative process that ties in closely with the ability to visualize and plan. This creative process helps the problem solver use unique and novel plans in problem solving that often result in better and more efficient solutions. Through my father's mentoring, I have been able to acquire these important problem solving skills and dedicate this thesis to him as a sign of my appreciation.

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Words cannot express my gratitude to the people and organizations who have contributed to this project. Without their assistance and support this project could not have been completed. Thinking reflectively on my experiences with these people provides me with many good memories. I only hope that I will be fortunate enough to participate in future projects with these high-quality individuals.

I consider my advisor, Dr. Richard A. Swanson, Professor of Industrial Education, a friend and a colleague. His encouragement, guidance, and editorial assistance contributed greatly to the quality of this document. Dr. Swanson's personal and professional qualities place him at the top of his field. I feel very privileged to have had the opportunity to work with someone of his stature. Dr. Swanson is also the Director of the Training and Development Research Center at the University of Minnesota which provided considerable support for this project. In addition to the financial support provided by the Center, it also provided the industrial contacts that were so essential to the success of this research project.

This study was also funded through the Minnesota Research and Development Center for Vocational Education (MRDC) at the University of Minnesota. I was fortunate that my research interests were closely aligned with those of Dr. Ruth G. Thomas who is Project Director of the Higher Order Thinking Skills project in the MRDC. I have considerable respect for Dr. Thomas. She impressed me with her knowledge of the problem solving literature and her ability to conceptualize a very difficult subject.

Without the support provided by Onan Corporation this project would not have been possible. Allen Jacobsen, Training Manager of the Onan Service Training School, was willing to open any and all doors to me. He

provided access to the subjects and apparatus used in this study and also allowed me to participate in formal training sessions which were invaluable during the task analysis portion of this project. I want to thank the technical trainers at the Onan Service Training School; Dr. Dave Johnson, Bill Orness, Keith Summers, and Ed Westerdahl. These subject matter experts were willing to spend considerable time and effort evaluating and administering many of the dependent measures that were developed for this project. Special thanks go to Keith Summers whose interest in technical troubleshooting kept him very involved with this project.

I consider Dr. Paul Johnson, Director of the Ph.D. program in the School of Management, an expert in the research of expertise. Through a Doctoral Seminar taught by Dr. Johnson, I was introduced to much of the major research done in the area of problem solving and expert system development. Dr. Johnson provided me with the conceptual base upon which I could build this study. I thank Dr. Johnson for his many insightful thoughts that can be found throughout this paper.

I thank the remainder of my committee, Dr. David Bjorkquist, Dr. Jane Plihal, and Dr. George Shappiro, for the assistance they provided. These people have influenced me more than they know through the courses and conversations we have had together.

Finally, I would like to thank my family for their support and encouragement. How much more difficult this project would have been without their influence. I regret the many hours I spent away from my wife and children. When I was not away physically I was certainly away mentally. An intensive project such as this certainly places a severe strain on a family. I am extremely fortunate to have such a loving wife. Jean's constant love and encouragement kept me going throughout this project. My children, James and Brian, are such a joy to be around. They showed genuine interest in my work and also provided me with the "lighter times" that were so valuable throughout this project. I also want to thank my parents, Vernon and Charlotte Johnson, and my wife's parents, Wayne and Jerry Welch for their love, concern, and encouragement.

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CHAPTER I

The Problem

The diagnosis of malfunctioning equipment and machinery is an important facet in our industrial economy. This nation's quality of life is dependent upon the ability of our workforce to identify and solve technical problems. The service sector of the nation's economy which has been steadily growing provides one example of the need for problem solving abilities in the workforce. As technology has advanced so has the complexity of most equipment. As a result, it is becoming increasingly difficult for people to know all there is to know about repairing equipment and machinery. The knowledge and cognitive process skills that are needed for troubleshooting and repair are becoming increasingly valuable. The problem, however, lies in our lack of understanding of the knowledge and skills that are required to perform the complex task of troubleshooting faulty equipment.

Recent research efforts have begun to provide an understanding of the knowledge and skills that are needed to successfully solve problems such as troubleshooting complex equipment. This type of research investigates and identifies human problem solving processes and has been used for two main purposes. First, problem solving research has provided a greater understanding of the capacities of human intelligence (Chiesi, Spilich, & Voss, 1979; Frederiksen, 1984; Kolodner, 1983; Larkin, McDermott, Simon, & Simon, 1980). Increased understanding of the ways people encode, store, structure, and process information while solving problems allows educators to develop more effective instructional programs. The second use of problem solving research has assisted in the development of expert systems (Bouwman, 1983; Fink, Lusth, & Duran, 1985; Good, 1984). Expert systems are intelligent computer programs that use knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. The creation of expert systems requires research that identifies the knowledge structures, production rules, and strategic processes that are used by human experts on specific tasks. Expert systems have been developed that diagnose diseases, locate mineral deposits, configure complex computer hardware, and aid mechanics in troubleshooting locomotives (Harmon & King, 1985).

Statement of the Problem

The major focus of this study was to examine the relationship between technical troubleshooting behavior and level of expertise of subjects who diagnose faulty technical systems. This investigation provided insight into the nature of expertise through a comparison of the cognitive and performance activities of expert and novice troubleshooters as they attempted to locate a fault in a technical system. In order to achieve the results of this study, the problem was divided into three broad research questions. The investigation of these three research questions identified the relationship between troubleshooting knowledge and skill and expert and novice levels of expertise. The specific questions related to the problem were:

1. HOW DOES LEVEL OF EXPERTISE RELATE TO THE DECLARATIVE KNOWLEDGE BASE THAT TECHNICAL TROUBLESHOOTERS BRING TO A PROBLEM SITUATION? This research question was been divided into two, more specific, sub-questions.
    1.1 HOW DOES LEVEL OF EXPERTISE RELATE TO KNOWLEDGE OF DOMAIN RELATED BASIC PRINCIPLES? This research question focused on the declarative knowledge base of experts and novices and sought to reveal significant knowledge differences between the two sample groups. Specific knowledge bases investigated included the electronic domain, magnetic domain, and mechanical domain.
    1.2 HOW DOES LEVEL OF EXPERTISE RELATE TO

TECHNICAL SYSTEM UNDERSTANDING? This research question examined the declarative knowledge base of expert and novice troubleshooters as it relates to their depth of understanding of technical systems. The specific components of this knowledge base include the identification of system components (what is it?), knowledge of component function (what does it do?) and operation (how does it do it?), and the relation of components to the operation of the total system (what happens to the system if the component fails to operate properly?).

2. HOW DOES LEVEL OF EXPERTISE RELATE TO THE PROCEDURAL KNOWLEDGE BASE THAT TECHNICAL TROUBLESHOOTERS BRING TO A PROBLEM SITUATION? Successful technical troubleshooters must be able to accurately and efficiently perform certain procedural operations while diagnosing ill-functioning technical systems. This research question sought to identify differences in the procedural knowledge base of experts and novices as they perform various test procedures, calculate using formulas, and obtain information from technical sources such as schematic diagrams, wiring diagrams, parts lists, and technical manuals.
3. HOW DOES LEVEL OF EXPERTISE RELATE TO TECHNICAL TROUBLESHOOTING PERFORMANCE? Because this investigation of performance involved the analysis of directly observable and indirectly observable troubleshooting behavior, this research question has also been divided into two sub-questions.
   - 3.1 HOW DOES LEVEL OF EXPERTISE RELATE TO DIRECTLY OBSERVABLE TECHNICAL TROUBLESHOOTING PERFORMANCE? This research question examined the troubleshooting performance of experts and novices as they diagnosed faulty technical systems. Specific variables investigated included success rate, time to solution, and

procedural skills.

3.2 HOW DOES LEVEL OF EXPERTISE RELATE TO INDIRECTLY OBSERVABLE TECHNICAL TROUBLESHOOTING PERFORMANCE? This research question sought to reveal the indirectly observable cognitive processes of experts and novices as they attempted to diagnose faulty technical systems. With the goal of gaining a greater understanding of the problem solving processes that are required for successful troubleshooting performance, this phase of the research study investigated the specific cognitive processes used while acquiring and interpreting information and while generating and evaluating potential hypotheses. Emphasis of the analysis was placed on the subjects' problem representations, cognitive structures (mental models), cognitive processes, and problem solving methods used during technical troubleshooting. Differences in these cognitive processes were examined and used to advance current theories of troubleshooting behavior.

Significance of the Problem

Once a greater understanding of the knowledge, skills, and cognitive processes that are required to solve complex, technical problems is obtained, effective training programs can be developed. Currently, most training programs are developed based on incomplete task analysis models. One type of task analysis model commonly used, behavioral task analysis, decomposes the task into observable behaviors. This provides the instructional developer with an understanding of the observable behaviors of troubleshooters but pays no attention to the internal workings of the troubleshooter's mind while working on problems. A second type of task analysis, rational task analysis, has been used to identify the thought processes of experts. This approach fails because it relies on the expert's retrospective account of the thought processes used during task solution

(Magone & Yengo, 1986). This approach merely identifies the cognitive processes that the expert thinks are being used but it does not necessarily result in the identification of the actual cognitive processes that were used during the solution of the task (Ericsson & Simon, 1984).

This research study was based on a cognitive task analysis model that takes the best of the behavioral and rational models and results in a deeper and more complete understanding of both directly observable and indirectly observable behaviors. Gott (1986) described three arguments for the use of cognitive task analysis over either behavioral or rational methods. First, cognitive task analysis can capture more of the substructure of complex technical skills. The development of complex skills requires the convergence of many subskills. Other task analysis methods can not reveal these subskills because skilled performers are often times unaware of what it is they are doing (Polanyi, 1962). Secondly, cognitive task analysis can provide an "ideal" model to guide the development of technical instruction. Complex technical environments require the development of internalized conceptual models that are used to explain system functioning (Kieras & Bovair, 1984; Magone & Yengo, 1986; White & Frederiksen, 1986). Cognitive task analysis can reveal these mental models while behavioral task analysis merely identifies performance without understanding. The third argument for cognitive task analysis concerns adaptiveness of instruction to the needs of the learner. Cognitive task analysis can help to predict where variations in the development of learner expertise can occur. Highly individualized instructional decisions can then be made as learners progress from concrete representations of surface or physical features to abstract representations of the functional and operational features of a problem.

As a result of this research, an identification and understanding of the knowledge, skills, and cognitive processes of technical troubleshooters has been gained. These results can now be used to develop more effective instructional programs to train technical system troubleshooters.

Limitations of the Problem

Two main limitations are evident in this study. First, the methodology used in this study requires the collection and analysis of extensive amounts of data (Ericsson & Simon, 1984). This data is composed primarily of the verbal protocols of experts and novices as they work through selected troubleshooting tasks. Each segment of the protocols must be scored quanitatively and qualitatively. Because of this large volume of data, it is practically and financially implausible to attempt to study a large sample population.

Secondly, because the goal of this study is to generate new knowledge about troubleshooting expertise, the availability of the population to be studied is extremely limited. Troubleshooting experts are a very select group and are not available for study in large quantities. This unique characteristic of the target population forces the researcher to select research subjects by means other than through common randomization procedures. This limitation should not place the usefulness of the study in jeopardy. The results of this study are not meant to be generalized to a larger population. Rather, the intent of this research was to learn about the troubleshooting behavior of discrete groups within a normally distributed population.

Definition of Terms

Cognitive task analysis -- An analysis procedure that examines the relationship between cognitive processes and behavior (Magone & Yengo, 1986).

Declarative knowledge -- The facts, principles and concepts that an individual knows (Anderson, 1980; 1982).

Expert -- In this study an expert is defined as a person who has developed, through a combination of education and experience, the knowledge and skills needed to perform well above the norm.

Expert system -- A computer system that performs at or near the level of a human expert (Harmon & King, 1985, p. 259).

Expertise -- The skill and knowledge possessed by some humans that result in performance far above the norm (Harmon & King, 1985, p. 259).

Hypothesis -- A possible solution to a problem that is generated based upon previous information that has been acquired and interpreted.

Ill-structured problem -- Problems that lack clear formulation, procedures for solution, and criteria for evaluating solutions (Frederiksen, 1984).

Knowledge acquisition processes -- The process of locating, collecting, and refining knowledge (Harmon & King, 1985, p. 262).

Mental model -- The symbolic networks and patterns of relationships used while trying to understand a problem.

Novice -- In this study a novice is someone who has a limited amount of knowledge and experience in a certain area. The term novice, as used in this study, is not used to describe someone who has no knowledge or experience in a certain area.

Problem solving -- Process in which one starts from an initial state and proceeds to search through a problem space in order to identify the sequence of operations or actions that will lead to a desired goal (Harmon & King, 1985, p. 264).

Procedural knowledge -- The skills an individual knows how to perform (Anderson, 1980; 1982).

Protocol -- A description of the activities, ordered in time, in which a subject engages while performing a task (Hayes, 1981, p. 51).

Technical Troubleshooting -- The sub-process of problem solving that involves the investigation of a fault in a technical system through generation and testing of hypotheses.

CHAPTER II

Review of the Literature

The problem solving literature contains an emormous amount of information which is based on differing philosophies. Of particular concern for this study is the research literature based on the cognitive science approach to human problem solving. Using the cognitive science literature as a limiting factor, this review has been divided into three broad categories. The foundational perspectives upon which this and many other research studies have been based will be discussed first. The discussion of these perspectives begins with a description of general human behavior and concludes with a detailed examination of problem solving theory and the nature of expertise. The second major category of this literature review involves the methodological concerns that must be addressed for this type of study. A model for investigating problem solving behavior is presented along with a discussion of various techniques for implementing the research model. The final part of this review involves a look at the literature pertaining to one discrete phase of problem solving, troubleshooting behavior. This discussion involves a description of the troubleshooting process and sets the stage for the data collection and analysis phases of this study.

Foundational Perspectives

The foundational literature in problem solving may be grouped into three major perspectives. These perspectives contain the knowledge and theories that support the current research efforts which describe the problem solving process. The first perspective provides several assumptions regarding general human behavior that are important to the study of problem solving behavior. The second perspective describes a cognitive science theory of problem solving that has provided the foundation for much of the current research in problem solving because of its ability to successfully describe the problem solving process of experts. The third perspective examines the current *theory of expertise*. These three major perspectives provide the groundwork upon which this study is based.

General Human Behavior

Before an effective investigation of problem solving behavior can proceed, three assumptions regarding general human behavior should be made. First, human behavior is thought to be purposive and goal directed. Behavior is determined by the goals and plans developed by an individual rather than being determined by external stimuli as proposed by the pure behaviorist view. This assumption is further supported by Harre' and Secord (1973) who suggest that people are able to initiate their own actions, can monitor those actions, and also have the power to monitor their own monitorings. This point implies the possession of an awareness of being aware which is fundamental to the problem solving behavior theories.

The second assumption looks at behavior as being adaptive to the environment. This point refers to the biological nature of the individual and suggests that people are able to change their behavior based upon the environmental context of their situation (Simon, 1981). Scribner (1984) observed this phenomenon while studying the working behavior of dairy workers. Scribner noticed that the worker's problem solving processes changed to fit the situation. The change in behavior was most apparent when the adaptation resulted in a savings in effort for the workers.

The third assumption suggests that behavior reflects the environment. It is not possible to understand the behavior of an individual through observation without regard for the environment. Because people have the power to adapt, they are able to modify their actions and goals when changes in the environment occur. If an attempt is made to understand the behavior of individuals without examining their environment, incomplete and inaccurate information will surely result (Simon, 1981).

Problem Solving Theory

Through research in the areas of cognitive psychology and computer science, a better understanding of the human problem solver has been gained. Cognitive scientists expend much of their energy trying to gain a better understanding of the ways that people attempt to solve problems (Simon, 1980). The results of this research has direct implications for industrial education and should be thoroughly examined.

One of the first major works on problem solving in cognitive science was conducted by Newell and Simon (1972). Their problem solving model is based upon the assumption that the human problem solver operates as an information processing system. This information processing system consists of three structures which are of importance to the study of human problem solving behavior. These three structures include the sensory register, short-term memory, and long-term memory.

The sensory register accepts information from the sensory organs (eyes, nose, etc.) and holds the information for a very short time. Because the sensory register experiences a memory decay in less than a second, information must be processed for storage into short-term memory (Bourne, Dominowski, & Loftus, 1979).

Short-term memory is the working memory for the information processing system and is where the conscious mental processes take place. Information is received from the sensory register, processed into short-term memory, and may be sent to the long-term memory. The short-term memory is limited in its ability to maintain storage. Information will decay within about 15 seconds unless something is done to prevent the loss. Constant attention or rehearsal are two weak strategies that help maintain information in short-term memory almost indefinitely (Bourne, et al., 1979).

The final structure within the memory system is the long-term memory. Long-term memory is believed to have an unlimited capacity for information. Both the content and the organization of the long term memory are thought to play an important part in successful problem solving (Egan & Schwartz, 1979; Larkin, McDermott, Simon, & Simon, 1980).

Newell and Simon (1972) explored the operation of the information processing system through the development of computer programs which simulated human problem solving behavior. They believe that problem solving can be understood by describing the environment in which it takes place. After the problem has been recognized and understood, a problem space must either be constructed or retrieved from long-term memory. It is within this problem space that the search for the solution is undertaken. A problem space consists of the following:

- Initial condition -- in which the given or starting conditions are represented.
- Goal condition -- in which the final goal condition is represented.
- Intermediate problem conditions -- consisting of new conditions that are generated by applying an operator to a condition.
- Operators -- the moves that result in a change from one condition to the next (Mayer, 1983).

The problem solving process in the Newell and Simon model begins with the input of information which becomes an internal representation of the problem. The problem solver then selects a particular problem solving method that has some relationship to the solution goal. If the problem solver is unable to find a solution, one of the following three options may be selected: (a) select another method, (b) select a different internal representation of the problem, or (c) abandon the problem.

The methods employed in the above model use various algorithms or heuristics to reach a problem solution. An algorithm is a procedure that guarantees a solution to a problem such as an algebraic formula or equation. The difficulty with the use of algorithms is that they are not available for most important problems and when they are they can actually be impossible to execute because of the large amount of memory search that is needed. Heuristics do not have the constraints that algorithms have although they do not necessarily guarantee a correct solution. Several types of heuristics have been identified in the problem solving literature (Hayes, 1981; Newell & Simon, 1972). Common heuristic methods include simplifying the problem, means-end analysis, working backwards, pattern recognition, and trial and error.

The Nature of Expertise

Many of the prior research studies in problem solving have attempted to identify the specific problem solving behavior of experts. The research has led to a greater understanding of the nature of expertise.

Expertise can most simply be defined as highly adaptive behavior. People who have expertise have a "power" that allows them to achieve results; to get the right answers. Expert behavior is also fluent and efficient. Experts are able to solve problems with very little physical or mental waste. They are able to get results in fewer steps and in less time. This particular phase of expertise becomes more recognizable when the constraints of human cognition are considered. A third characteristic of expert behavior relates to its flexibility and robustness. Expertise is adaptable or generative behavior. Experts are able to generate new knowledge in new situations through their great depth of knowledge and experience. Kolodner (1983) also supports this view by stating that human experts are able to introspect about their knowledge and learn from past experience.

While it can oftentimes be easily determined who has expertise, it is not as easily determined how expertise is developed. One developmental model for the acquisition of expertise consists of three stages: (a) cognition, (b) guided practice, and (c) automated behavior (Fitts & Posner, 1967). The cognition stage is where the novice asks "What must I do?" This is the most basic learning stage where the learner tries to determine what must be done and how it is done. The cognitive development required for the attainment of this stage can be reached through instructional demonstration and socratic teaching methods with feedback as needed. An individual must remain in this stage until the task can be done correctly.

In the second stage of the model for the development of expertise an individual must practice the task until it is done fluently and efficiently. Polanyi (1962) discusses the concept of skill acquisition in this stage as being similar to a master/apprentice system of knowledge transfer. Polanyi argues that through non-verbal interaction, an expert is able to focus the attention of the novice on certain aspects of the task. This assistance results in a shift from a subsidiary awareness to a focal awareness where the novice, who formerly concentrated on the specific sub-components of the task, begins looking at the task from a gestalt perspective. This switch in awareness leads to the third stage of the expertise acquisition model.

The automated behavior in the third stage of the model results from the extensive practice performed in the second stage. By entering the automaticity stage, the novice has shown evidence of expertness by the ability to produce expert-like behavior. The novice has mastered the sequences of behavior that are required to complete the task in a proficient manner and may be considered an expert with the particular task although the label of expertise may not be appropriate at this time. Because the task may now be completed almost automatically, the individual's short term memory component is freed up and may be used for other purposes. At this stage the individual performs somewhat automatically because of the development of what Polanyi calls tacit knowledge. The individual is no longer able to report what knowledge is being used to complete the task. Tacit knowledge creates a problem for those who try to understand expertise because they are not able to collect information from experts that accurately specifies the rules and strategies used to complete the task. The expert will oftentimes be able to express the procedures that are "thought" to be used but these are not necessarily the actual methods employed.

Finally, it must be understood that the above model for the acquisition of expertise does not imply that the individual who goes through these three stages will automatically acquire expertise. In most cases expertness will certainly be developed, but the current theories do not adequately specify the "mystical ingredient" that is needed to advance from expertness to expertise.

Where the expertise is and how it is used is an important question within the framework of problem solving behavior. Newell (1981) argues that expertise can be found at a level he calls the knowledge level. Newell's theory of expertise suggests that the expert relies on principles to control problem formulation and representation. These principles are abstract rules that are located at the knowledge level and allow the individual to reformulate the problem or look at it from another perspective using a different representation. This knowledge level contains the knowledge and skill that controls the individual's actions toward a goal. By using the knowledge at the knowledge level, an expert is able to look at the problem or task differently than a novice would and is able to choose a problem solving method that is effective. Kolodner (1983) varies with Newell on this point by suggesting that expertise is based on expert reasoning about "cases" rather than rules. Her evidence for this view is based on the fact that experts do not work slower as more information and experience is gained. If expertise were based solely upon reasoning about rules, Kolodner feels that the search time needed for solutions would increase as more was learned. Because experts seem to be able to work faster as they gain more information and experience suggests an important organization of information within the human memory system. Newell does not explicitly address the issue of organization at the knowledge level although it seems to be an important concern to investigate.

The organization or structure of the knowledge in human memory systems has been the focus of research in recent years. Current theory suggests that human memory consists of two parts; (a) knowledge bits, and (b) the organization of those knowledge bits (West, Fensham, & Garrard, 1985). Typically, the cognitive structure is represented as a complex organization of nodes connected by links (Larkin, McDermott, Simon, & Simon, 1980). Nodes are used to represent physical objects, conceptual entities, or descriptions of the objects. Links are used to describe the relationship between two nodes (Harmon & King, 1985). The graphic representation of this knowledge structure is usually called a semantic network (Harmon & King, 1985) or cognitive map (Novak & Gowin, 1984).

Current theory suggests that an expert's knowledge base is organized much differently than the novice's. Chi, Glaser, and Rees (1982) examined verbal protocols of experts and novices who were solving elementary physics problems. Their results show that both groups have rich knowledge bases related to physical configurations and properties although the experts have additional knowledge related to the problem solution based on major laws and principles. Egan and Schwartz (1979) conducted a similar study of expert and novice knowledge structures and their influence on the subject's ability to recall symbolic drawings. Subjects from each group were asked to review electronic drawings and were later asked to reconstruct the drawings from recall. The results showed that when presented with drawings that had random placement of electronic devices in a circuit, the experts did not perform better than the novices. However, when presented with realistic drawings, the experts were able to recall significantly more of the drawing than the novices. This study suggests that the memory of the expert electronic technicians was structured based on "conceptual" chunks. The experts were therefore able to recall portions of the drawings as chunks of information (i.e. amplifier circuit, tuner circuit, etc.) rather than as individual components. This study replicated an earlier study which showed that chess masters have a better recall of the placement of pieces from actual games but are not better than novice chess players when asked to recall piece positions from random board layouts (Chase & Simon, 1973).

Cognitive structures have also been looked at as forms of schemata or mental models. Schema theories suggest that the knowledge structure or schema of the individual may be used to help people recall information by tracing through the structure. Anderson, Spiro, and Anderson (1978) investigated the nature of recall improvement through the use of two written passages; a fine restaurant script and a supermarket script. Each of the two scripts mentioned the same 18 food and beverage items. Subjects were randomly assigned one of the two passages to read and were later asked to recall the entire passage in correct order. The results showed that food and beverage items that have a high probability of being ordered in a restaurant (e.g. salad, entree, etc.) were more likely to be recalled by the subjects who read the restaurant passage. It is thought that the restaurant passage invoked a restaurant model or script which was used to classify the food and beverage items in memory and therefore were more likely to be recalled.

Other studies have looked at schemas or mental models as organizing factors for knowledge. Kuipers and Kassirer (1984) investigated their hypothesis that physicians have a mental causal model of their patients. This model is thought to contain descriptions of body mechanisms and how they influence each other. Evidence is provided through the use of a computer program that simulates the physician's responses based on the hypothesized mental model. Kieras and Bovair (1984) have also investigated the nature of mental models. They were interested in determining what role mental models play in learning how to operate an unfamiliar piece of equipment. In this case, the mental model relates to the understanding of the device in terms of its structure and processes. The results of this study suggest that a mental model is not needed for procedures that are very easy although for more difficult procedures, the mental model is used to provide specific inferences about what the operating procedures must be. Other studies have investigated the importance of mental models for helping develop understanding of systems and to aid in troubleshooting faulty equipment (Bouwman, 1983; Lajoie, 1986; Logan & Eastman, 1986; White & Frederiksen, in press).

Methodological Concerns

Problem Solving Research Model

Based on the three problem solving perspectives that have been discussed, a model for the investigation of problem solving behavior requires that three components be considered (Johnson, in press). This problem solving research model includes the problem, the problem solver, and the problem solving process. When investigating problem solving behavior, each of these three components need to be thoroughly examined. The understanding of each component is necessary in order to achieve an accurate description of problem solving behavior.

The problem. The first component of problem solving behavior that must be understood is the problem. This component includes various variables related to the problem such as the type of problem, the amount of problem definition provided to the problem solver, and the context in which the problem occurs. Greeno (1978) attempted to provide the concepts needed to organize the types of problems that are faced by problem solvers. Greeno proposed three types of problems: problems of inducing structure, of transformation, and of arrangement. Greeno admits that this typology cannot be used to classify all problems although he states that most important problems have components of these types. Cote (1984) attempted to synthesize the results of various research studies by dividing problems into those of analysis, synthesis, and evaluation. Cote's categorization is not satisfactory because of the large amount of overlap between the three types of problems. It is difficult to imagine an important problem that does not include all three of Cote's categories. Further research is needed to develop a satisfactory taxonomy of problem types.

The amount of problem definition and structure also need to be determined to understand problem solving behavior. The problem can be placed on a continuum ranging from a well-structured problem to an ill-structured problem. A well-structured problem is one that comes with a well defined problem space and has a definite criterion for testing any solution while an ill-structured problem is poorly defined, has some conditions within the problem that are not known, and no clear criterion for testing solutions is available (Simon, 1973). Frederikson (1984) suggests that the well-structured to ill-stuctured continuum may be too simple. He proposes three categories; (a) well-structured problems that are clearly formulated, have a known solution method, and have criteria for testing solutions, (b) structural problems that require productive thinking and are similar to well-structured except some crucial step is missing and must be generated by the problem solver, and (c) ill-structured problems that lack clear formulations, procedures, and testing methods. Frederiksen's categories do not appear to be unique when one considers that his suggestions only define one more category on the continuum. Surely more thinking is needed in this area to further define the problem definition continuum.

The quantity of problem definition that is given to a problem solver greatly influences the choice of method that will be used to solve the problem. For example, problem solvers are more likely to use heuristic methods rather than algorithms to solve ill-structured problems because the determination of the correct algorithm is difficult when problem information is missing.

The context of the problem can greatly affect the type of information gathered by the researcher. On one hand, if a problem solver is given a realistic problem, the investigator will discover information about the problem itself and the methods the problem solver uses to find a solution.

On the other hand, if an unrealistic problem is given to a problem solver (as is traditionally done in psychology), the investigator will not learn anything that applies to the real world but will gain insight into the problem solver's inner environment. A third type of problem, generative problems, will require the problem solver to transfer existing knowledge to new situations and will result in the investigator learning about the deep rules or mental models used by the problem solver (P. E. Johnson, personal communication, April, 1985). Although the investigator may be observing behavior in all three cases, the type of task given to the problem solver will result in different types of information being gained.

The problem solver. A second component needed to understand problem solving behavior is the problem solver's knowledge and skill level and the constraints of the human information processing system. Newell and Simon (1972) advocated the emphasis on the information processing capabilities of humans in their studies on problem solving. Newell and Simon recognized that a major limitation in the problem solving ability of individuals was their limited memory capacity that affected the quantity of data and the allocation of resources during problem solving. The short term memory component has the limited capacity that is a constraint to behavior. This limited capacity must be considered when attempting to understand problem solving behavior. The importance of this point can be understood by looking at the difference between the novice and expert. The novice is aware of all the facts and procedures that are required to perform a problem and, because of the limited short term memory capacity, is only able to focus on specific, individual components of the problem. In contrast, the expert through chunking of information and through automaticity, is able to free up the short term memory and thereby operate more efficiently and effectively.

The long term memory is another information processing component that can be a constraint to problem solving behavior. Kolodner (1983) discusses the semantic and episodic memories and argues that even if a novice and expert had the same semantic knowledge (facts), the expert's experience would enrich the episodic memory which would provide better use of the semantic knowledge. Therefore, an individual's long term memory must also be examined if an attempt is made to understand behavior.

The problem solver's goals or purposes must be understood in order to comprehend problem solving behavior. The investigator must determine what the problem solver perceives as the goal of the problem as this will affect the resultant behavior. The investigator should also attempt to reveal the driving force behind the problem solver's actions which can affect problem solving behavior. Von Cranach, Kalbermatten, Indermuhle, and Gugler (1982) discussed the hypothesis of people as goal directed organisms. This type of goal directed theory points out the importance of determining the goals or purposes of problem solvers if an attempt is made to understand their problem solving behavior. Simon and Simon (1979) conducted a study that reveals the importance of considering the problem solver's knowledge base and goals. "Real-world" textbook problems were presented to subjects of differing backgrounds. One subject analyzed the problem strictly as a textbook problem by representing and solving it as an abstract problem. The second subject analyzed the problem as a realistic problem by changing the stated problem into a more important one. In this study, two subjects who were knowledgeable in different areas used completely different approaches to solve the problem.

The problem solving process. The processes used by individuals must also be looked at if an understanding of their problem solving behavior is to be gained. If an individual's problem solving behavior is to be understood it is important that the investigator know what methods may be used. Through a detailed cognitive task analysis, the researcher will be able to determine what processes are likely to be used for the specific problem that will be presented and will be able to use those results to guide the investigation of problem solving behavior. Most possible problem solving methods can be divided into weak and strong methods. Weak methods are for general use and include such modes as trial and error and means-end analysis. Strong methods are useful only in specific problems and include algorithms and certain powerful heuristics developed for the specific problem area. These strong heuristics can focus on the rules used to solve problems and can support the individual's knowledge schema or the representation of the problem.

Application of the Model

Using the problem solving research model as a guide, several methods can be used to learn about problem solving behavior. Harre' and Secord (1973) provide the conceptual justification for these methods through their "ethogeny" approach. This approach makes use of the subjective accounts of problem solving actions and analyzes these in the context of the situation in which they actually occur. They reject the experimental research methods because they provide information about a "typical" person based on group results rather than looking specifically at an individual's behavior. They also are concerned about the traditional experimental methods that impose situations upon people to see how they react rather than investigating people in situations that are common and normal.

The methodology used for the investigation of problem solving behavior should take advantage of the various information sources that are available. These sources of information can be accessed through a combination of three methods: (a) analyzing the environment and the problem through a task analysis, (b) direct observation of the problem solving behavior, and (c) verbalization of the problem solving process by the problem solver (Harre' & Secord, 1973).

The first two methods, task analysis and direct observation will provide complete information about the knowledge and skill needed to solve the problem, potential problem solving processes, and a detailed decription of the problem space that the problem solver must search through to find a solution. The cognitive task analysis method described earlier is the most powerful task analysis method available for investigating problem solving behavior (Gott, 1986; Magone & Yengo, 1986; Resnick, 1976; Stephens, Bhaskar, & Dillard, 1981)

In conjunction with cognitive task analysis, the third method for investigating problem solving behavior, collecting and analyzing verbal protocols, can provide very rich information into the knowledge, skill, and cognitive processes of the problem solver. Ericsson and Simon (1984) and Hayes (1981) provide discussions of the effectiveness and proper techniques for collecting verbal protocols. This method is not effective if the investigator merely asks the problem solver to tell how the problem was solved. The result will be the problem solver telling how the problem was thought to be solved and is not necessarily a description of the actual processes used. This difficulty primarily occurs, when investigating expert behavior, because their expertise allows them to consciously attend to less information than novices do. Since we are only able to report information that is attended to in short-term memory, retrospective accounts cannot accurately describe the events of problem solving. A better technique is to have the problem solver "think aloud" which will provide accurate descriptions of the problem solving sequence and lines of reasoning. While there is considerable controversy over the accuracy of the verbalization of mental processes (Ericsson & Simon, 1984; Kellogg, 1982; Nisbett & Wilson, 1977), this method can be very powerful if used correctly. If verbal protocols are collected under the right conditions, they will closely reflect the form and sequence of thought processes that occur during problem solving (Ericsson & Simon, 1984).

The various methods proposed in the framework for the investigation of problem solving behavior should be used together to gain as much information as possible. Each method could be expected to reveal unique information and should also support the results of the other methods. Through the use of this framework, the investigator would be able to examine expert behavior during various domain-specific tasks which could lead to an understanding of the knowledge and skill required to successfully solve problems.

Troubleshooting Behavior

In the early stages of cognitive psychology research into problem solving behavior, most of the studies investigated problems that were well-defined, unrealistic, and domain-independent. Typical problems studied were the Tower of Hanoi Puzzle (Simon, 1975), Cryptarithmetic problems (Newell & Simon, 1972), and "Go" playing ability (Reitman, 1976). Over recent years, the topics of study have changed to problems that are ill-defined, realistic, and require domain-specific knowledge for their solution. Examples of these types of problems include medical diagnosis (Elstein, Shulman, & Sprafka, 1978; Kuipers & Kassier, 1984), financial accounting (Bouwman, 1983), and electronic troubleshooting (Rasmussen & Jensen, 1974).

Using the foundational perspectives and the methodological concerns as the groundwork for these studies, a clearer picture of the knowledge and skill requirements for solving domain-specific problems has emerged. Of particular interest to this study are the recent research efforts to describe the problem solving process of diagnosis or troubleshooting.

Technical Troubleshooting Model

In many types of problem solving a goal is apparent and specific which results in the problem solver using various methods such as means-end analysis. However, in problems such as troubleshooting where a goal is not apparent or specific, the problem solver is more likely to use a hypothesis testing method (Sweller & Levine, 1982). Other research on troubleshooting technical systems support this thought (Bouwman, 1983; Elstein, Shulman, & Sprafka, 1978). Through a synthesis of these and other studies found in the problem solving literature, a Technical Troubleshooting Model has been developed (see Figure 1). It is hypothesized that this model portrays an accurate representation of the cognitive process flow of the troubleshooter when working on a technical problem.

The Technical Troubleshooting Model is divided into two main phases; (a) hypothesis generation, and (b) hypothesis evaluation. In phase one of the model, the troubleshooter begins the problem by acquiring information from internal or external sources that can be used to represent the problem (see Figure 2). As an internal source, the individual's long term memory contains both declarative knowledge and procedural knowledge (Anderson, 1980; Anderson, 1982; Glaser, 1984). The external sources of information could include job aids, technical support, technical evaluation through test procedures and operational adjustments, and sensory evaluation which includes visual, auditory, tactil, and olfactory inspections. This step of the model involves the acquisition of information into the sensory register, the very short term memory that retains information for less than a second. Before the information can enter the individual's short term memory, the information must be attended to. This cognitive action occurs in the second step of the model, information interpretation. In this step, the troubleshooter interprets the relevance of the information that has been acquired and processes it by relating the information to the troubleshooter's cognitive structure and synthesizing the information into a meaningful whole.

The flow through the information acquisition and information interpretation phases of the model is an iterative process. As information is acquired and interpreted, more information may be needed before the troubleshooter can proceed to the next step, hypothesis generation. Once enough information has been obtained, the troubleshooter will then generate one or more hypotheses about what the potential problem might be (Elstein, Shulman, & Sprafka, 1978; Frederiksen, 1984). In the second

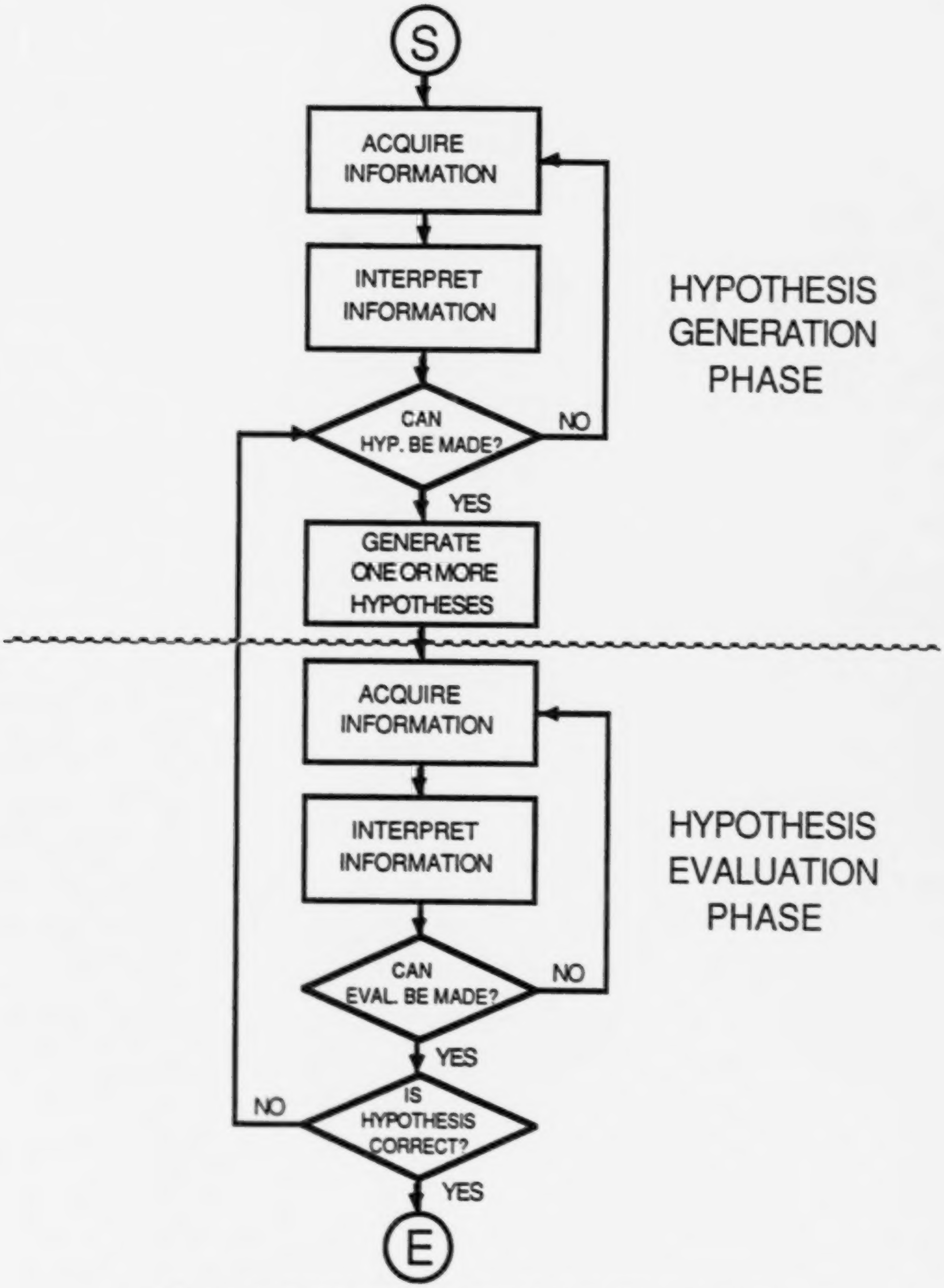

S
ACQUIRE INFORMATION
INTERPRET INFORMATION
CAN HYP. BE MADE?
NO
YES
GENERATE ONE OR MORE HYPOTHESES
ACQUIRE INFORMATION
INTERPRET INFORMATION
CAN EVAL. BE MADE?
NO
YES
IS HYPOTHESIS CORRECT?
NO
YES
E
HYPOTHESIS GENERATION PHASE
HYPOTHESIS EVALUATION PHASE

Figure 1. TECHNICAL TROUBLESHOOTING MODEL

S. D. Johnson -- 1987

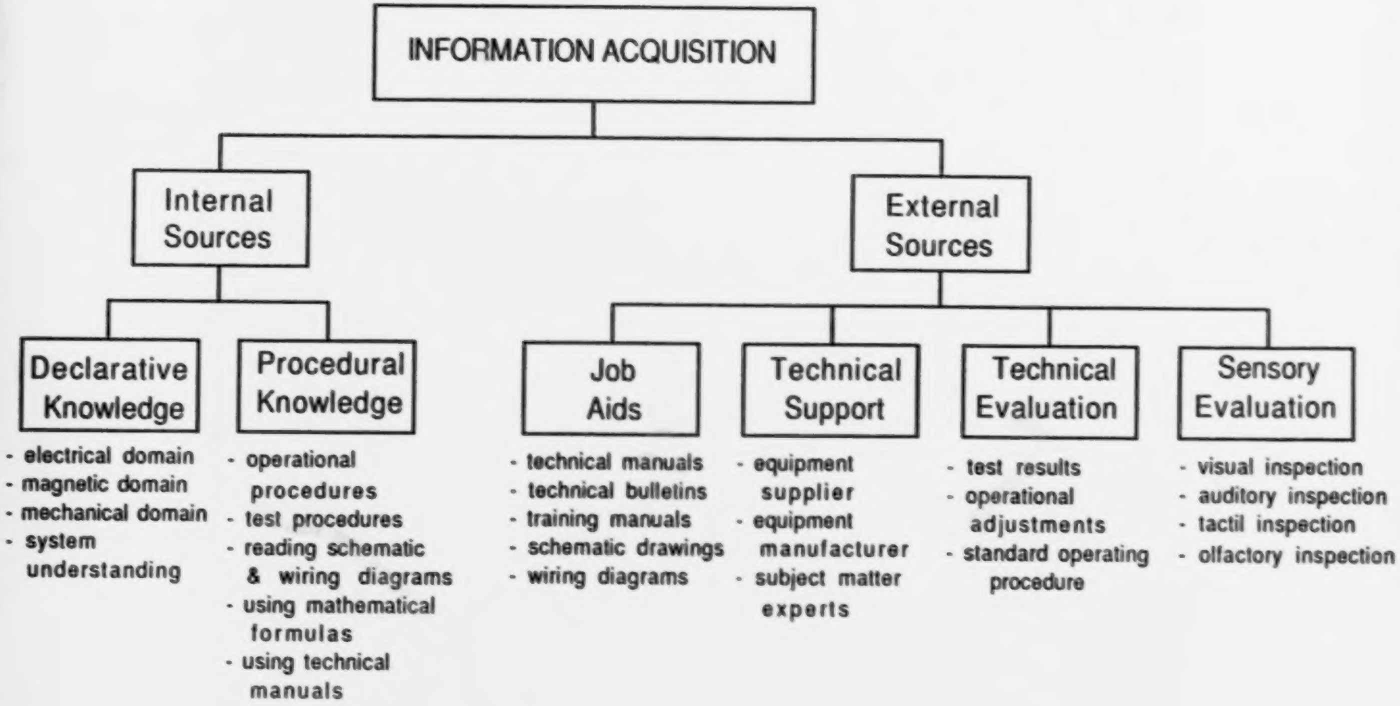

INFORMATION ACQUISITION
Internal Sources
External Sources
Declarative Knowledge
- electrical domain
- magnetic domain
- mechanical domain
- system understanding
Procedural Knowledge
- operational procedures
- test procedures
- reading schematic & wiring diagrams
- using mathematical formulas
- using technical manuals
Job Aids
- technical manuals
- technical bulletins
- training manuals
- schematic drawings
- wiring diagrams
Technical Support
- equipment supplier
- equipment manufacturer
- subject matter experts
Technical Evaluation
- test results
- operational adjustments
- standard operating procedure
Sensory Evaluation
- visual inspection
- auditory inspection
- tactil inspection
- olfactory inspection

Figure 2. Sources for Information Acquisition

S. D. Johnson -- 1986

phase of the model, the troubleshooter evaluates the hypotheses that have been generated (Elstein et al. 1978). This phase involves the acquisition and interpretation of additional information to confirm or disconfirm the hypotheses (Frederiksen, 1984). As the troubleshooter attempts to evaluate the hypothesis, a search for relevant information will begin. It is expected that three types of search methods will be used by the troubleshooter during this phase of the process (Rasmussen & Jensen, 1974). The first search method is a topographical search. Here the troubleshooter is expected to work in a linear direction through the system, taking measurements at various points. A schematic or wiring diagram is typically used as a reference to guide the topographical search. The second type of search is a functional search. When using a functional search method, the troubleshooter observes the function of the system and then proceeds to the specific sub-system based upon the acquired information. This type of search is useful for systems that have several sub-systems. The third type of search is by the mental evaluation of a fault. This search method is based on experience and uses a mental model of the system as a reference and guide.

It is expected that the troubleshooter will use procedures that require the least amount of cognitive effort (Gott, 1986; Rasmussen & Jensen, 1974). Because of this, the topographical and functional searches are expected to be used more frequently because rapid good/bad checks are made which require very little cognitive processing. However, when these simpler search methods do not produce results, it is expected that the troubleshooter will need to use a more powerful, yet more cognitively difficult, method such as the search by the evaluation of a fault. When using this search method, the troubleshooter must deal with the actual internal functioning of the system by using experience to recognize faults, knowledge of the general behavior of the system, and causal reasoning skills to determine what part is causing the fault.

In addition to the types of search methods that may be used, the type of information that is sought is important to consider. Several researchers have pointed out a major problem that subjects have when attempting to evaluate their hypotheses (Bruner, Goodnow, & Austin, 1975; Moshman, 1979; Mynatt, Doherty, & Tweney, 1977; Wason & Johnson-Laird, 1972). These studies reveal that hypothesis evaluators are more likely to look for evidence that supports the hypothesis rather than evidence that will falsify it. Evidence suggests that troubleshooters will be better able to reject incorrect hypotheses when they search for and obtain falsifying information (Mynatt, Doherty, & Tweney, 1977).

Following the hypothesis evaluation, a decision point will be reached. If it has been confirmed that a correct hypothesis has been generated, the troubleshooter can then end the troubleshooting process and proceed to a repair mode. However, if a correct hypothesis has not been generated, the troubleshooter will then cycle back to phase one of the model to select another hypothesis to evaluate or to acquire and interpret more information which can lead to the generation of new hypotheses which can then be evaluated.

To summarize this literature review, the foundational perspectives provide the underlying assumptions for human behavior in problem solving situations upon which this study is based. These perspectives also include the major theory of problem solving and detailed descriptions of expertise. The cognitive science approach to the study of problem solving provides the methodological rationale and guidance for this study of problem solving behavior. Very powerful methods have been described which provide extremely rich data concerning the knowledge, skill, and cognitive processes of problem solvers. At a much finer level of description, the troubleshooting literature provides the detailed information that is needed to adequately plan and organize this study so specific aspects of the troubleshooting process can be addressed and revealed.

CHAPTER III

Method

This study was divided into two separate, but related investigations. The first investigation was designed to identify differences in the knowledge base of expert and novice technical troubleshooters. The domain specific knowledge that troubleshooters bring to a problem situation was the focus of this phase of the investigation. Because this phase of the study was interested in non-troubleshooting knowledge, the data for this investigation was collected independent of a troubleshooting task. The second investigation examined the knowledge, skill, and cognitive process differences between expert and novice technical troubleshooters. This second phase of the study investigated actual troubleshooting behavior and required the subjects to perform in realistic troubleshooting settings.

Subjects

Two groups of subjects were selected from several distinct populations. A novice group of five subjects was chosen from a large population of service technicians who diagnose and repair faulty generator sets as a major portion of their work. The novice subjects were selected from a group of service technicians that were enrolled in the Small Products Training Courses delivered by the Onan Service Training School in the winter of 1987. The Onan Service Training School has a 25 year history of providing instruction in the service, maintenance, and repair of the generator sets manufactured by Onan Corporation. The students who attend the Service Training School come from all areas of the United States and are typically employed by distributors and dealers of Onan Corporation products.

No attempt was made to randomly select subjects from the class rosters. According to the Onan Training School instructors, class members typically display a wide variance of expertise (K. Summers, personal communication, November 11, 1986) and a randomization technique would only decrease the homogeneity of the final group. Because this group of subjects must be non-expert at troubleshooting generator sets, the variability within the class rosters must be controlled. To help ensure a homogeneous novice group, subjects were researcher selected based upon specific criteria (e.g. amount of experience and education). A questionnaire was mailed to all service technicians enrolled in Onan Corporation's Small Products Training Courses in the winter of 1986 (see Appendix A). The questionnaire provided information concerning the experience and education level of the enrollees. In addition, a short interview was used to obtain further information about the level of expertise of each technician enrolled. The questionnaire and interview data were then used to select the five technicians who were classified as novices.

Five expert subjects were selected from three populations within Onan Corporation. One population consisted of service representatives that answer questions and provide technical assistance for the service technicians that are in the field. Two expert service representatives were selected. A second population of experts consisted of manufacturing technicians who troubleshoot failed generator sets that have not passed the operational tests conducted at the end of the manufacturing phase. This group of experts, as a major portion of their work, take faulty generator sets from the test station, diagnose the fault, and make repairs so the unit can be delivered to a distributor in a working condition. Two troubleshooting experts were selected from the small population of troubleshooting technicians at Onan's main facility. A third population of experts consisted of technicians who work with the design engineers. One expert was selected from this population.

Two criteria were used for the selection of the subjects; experience and education. The experience variable was divided into three areas -- generator, mechanical, and electrical experience. The expert group had much more experience with generators and electricity. The experts had an average of 11 years of generator experience while the novices averaged only 1/2 year of experience. For electrical experience the experts averaged 9.5 years and the novices averaged 2 years of experience. The groups differed less in the years of experience in mechanical areas. The experts averaged 10.5 years and the novices averaged 5.25 years. The education variable consisted of formal education in vocational schools, the military, colleges, and factory training schools. The experts totaled nearly 6 years of formal education with the bulk of those years taken in vocational schools. The experts also had taken several courses through factory training schools. The novices totaled only 8 weeks of formal training in their area of work. The bulk of this education was made up by one novice who had 6 weeks of military training.

The expectations of the study for each of the subjects were explained individually to each subject. A consent form which described those expectations was then given to each subject to sign (see Appendix B).

It is important to acknowledge a major difference between this study and past research which has examined differences in expertise. Many of the former studies have selected subjects at the extremes of the expertise continuum and have labeled those groups as experts and novices. This has resulted in the identification of very definite differences between the two groups. This study differed in that the two groups of subjects were expected to be closer together in their level of expertise. This was expected because the sample groups were obtained directly from the workforce. In the workforce, service technicians need to maintain a certain level of competence in order to retain their jobs. If their performance falls below the expected level they are either terminated or transferred to a job where they can perform satisfactorily. Since all subjects were expected to have a moderate to high level of expertise, the label "novice", which implies a very limited amount of expertise, could be misleading. Refer to the definition of terms in Chapter 1 for the definition of the term novice as used in this study.

Apparatus

The equipment used for this investigation were electric generator sets manufactured by Onan Corporation, Minneapolis, Minnesota. Electric generator sets are used to supply electrical power for many applications including building standby systems, boats, recreational vehicles, and contractor's job sites. The specific generator set used in this study was a BGE series RV Electric Generator Set that is used primarily in recreational vehicles (see Figure 3). The BGE, commonly called the Emerald, is a newly designed generator set that is based on the most current technology available.

A generator set is an extremely technical piece of equipment that requires service technicans to have a large knowledge base of both declarative and procedural knowledge. Generator sets cover electrical, magnetic, and mechanical domains of knowledge and are used in millions of applications throughout the world. As with any technical device, breakdowns occur that must be repaired by qualified and experienced personnel. If generator sets cannot be quickly repaired, expensive and potentially dangerous situations can occur.

Investigation 1

Purpose

The purpose of Investigation 1 was to identify non-troubleshooting knowledge differences between expert and novice technical troubleshooters. This investigation examined the domain-specific knowledge differences while the subjects were not actively involved in a technical troubleshooting situation.

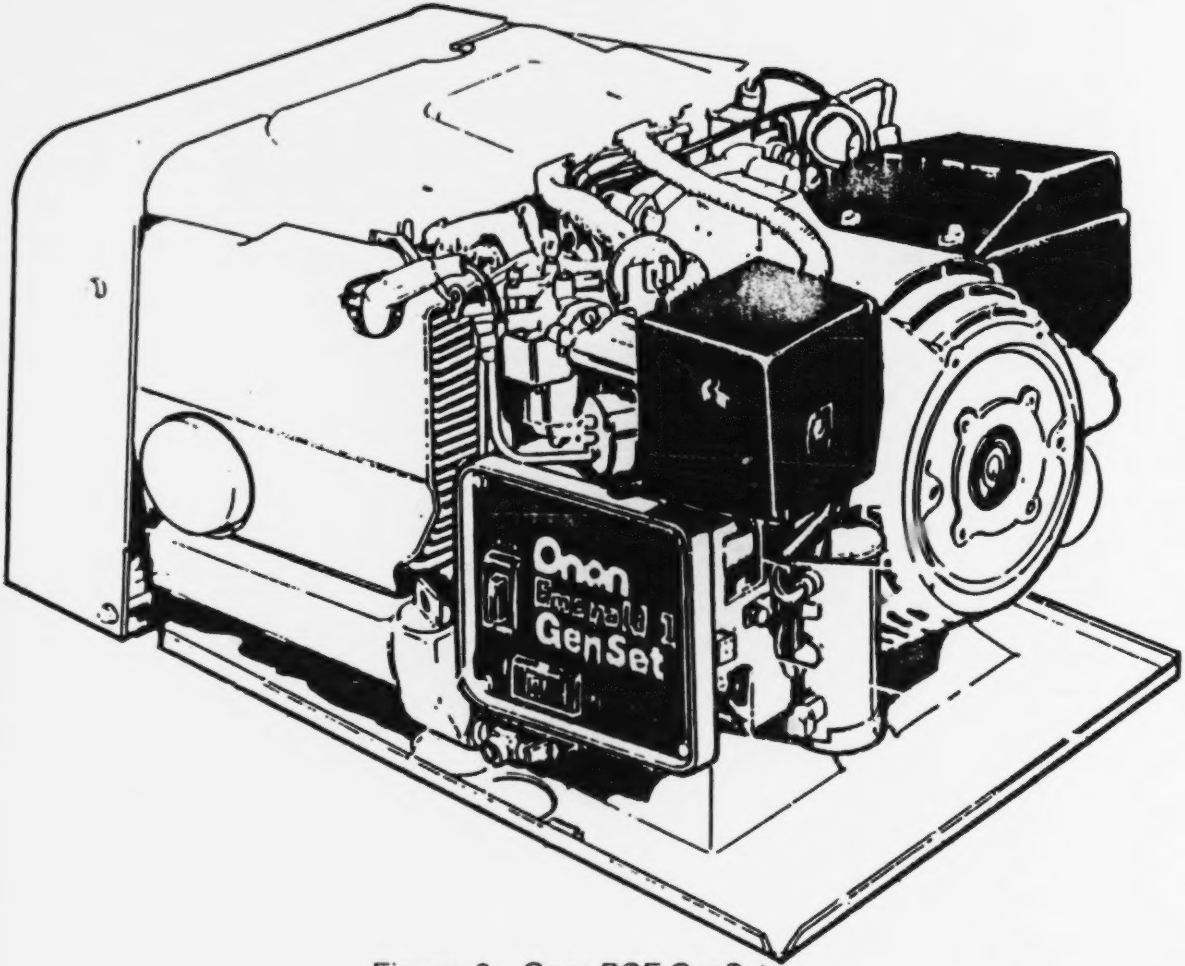

Onan
Emerald 1
GenSet

Figure 3. Onan BGE GenSet.

Procedure

Technical preparation. Before the development of the specific dependent measures, some preliminary analysis work had to be done. The Training Technology System (TTS) advocated by Swanson and Sisson (1983) was used to guide the specific task analysis work that was done. The Training Technology System provides an organized and complete method for the analysis, design, development, delivery, and evaluation of industrial training. This study used the work behavior analysis portion of the TTS to provide the researcher with an understanding of the generator set systems and to clarify the domain of knowledge and skills that are needed to operate and repair generator sets (Swanson & Gradous, 1986).

Dependent measure development, collection, and analysis. Following the preliminary analysis work, specific dependent measures were developed. These measures provided the quantitative data needed to identify knowledge differences between the expert and novice subjects. Both declarative knowledge and procedural knowledge were investigated in this portion of the study.

Two separate measures were developed to identify declarative knowledge differences between the two groups. The first was used to quantify the subjects' knowledge of the basic principles that underlie the operation of a generator set. This measure covered the electrical, magnetic, and mechanical domains that underlie the three major systems within a generator set: engine, generator, and control. The domain sampling theory (Nunnally, 1978) was used to develop this measure. This theory postulates that for every trait there is a domain of items which measure that trait. The task analysis and a review of relevent textbooks and training materials was used to identify the content of the three domains to be investigated. Alternative-choice items were written that represent a sample of each domain. The basic principles test was administered to a group of 50 Onan Training School students as a pilot to provide data for item analysis. The item analysis was used to identify good and poor test items. Specifically, the difficulty of each item, amount of discrimination, and the quality of the distractors was analyzed. The results of the item analysis were used to revise the test into its final form (see Appendix C).

Using the pilot test data, the reliability of the test was calculated using SPSS^x (1986) to determine if the test had a desirable level of internal consistency. Because only one form of the test was developed, because it was administered only once to the subjects, and because the items were scored dichotomously, the K-R^{20} formula was used (Brown, 1983). Reliability estimates for the total Basic Principles Exam which consisted of 50 items was .78. Subscore reliability estimates for the three subscales of mechanical, magnetic, and electrical principles were .60, .65, and .73, respectively.

The content validity of the test was established to determine if the test items represented a sample of the three domains of interest. Guion proposed five conditions that must be met if a test can be said to have content validity: (1) the content domain must be described in terms of behaviors that have generally acceptable meanings; (2) the domain must be described unambiguously; (3) the domain must be relevant to the intended use of the test; (4) qualified judges must agree that the domain has been adequately sampled; and (5) responses must be reliably observed and evaluated (in Brown, 1983, p. 136). Conditions one, two, three, and five were established during the test construction phase. Condition four was met using the method advocated by Martuza (1977). Following Martuza's method of content validation, two content specialists from Onan's Service Training School were given the domain definitions and the test items (see Appendix D). They were asked to review each item and rate the relevance of each item to the appropriate domain on a three point scale which corresponded to the terms very relevant, relevant, and not relevant. They were also asked to identify any important omissions in the coverage of the domain. The data were used to determine which items were valid samples of the domain of interest. Items that both content specialists thought were either "very relevant" or "relevant" to the domain were selected to be included in the exams. Any items that were rated "not relevant" by one or both raters were not included in the exam.

A second measure was used to quantify the subjects' knowledge of the systems within the generator set. Subjects were presented with selected components from each of the three domains of interest and were asked to identify the parts, describe their operation and function, and describe the relation of each part to the system as a whole. They were also asked to describe the processes involved which produce electrical output in a generator. The verbal responses were recorded on an audio cassette recorder and were transcribed for analysis. Subjects were also given an exam on the control system within the generator. This was an existing exam used in the Onan Training School.

Several measures were used to identify differences in the procedural knowledge of the two groups. These measures were used to quantify the subjects' knowledge of procedures for performing basic operations that are commonly performed by service technicians. This knowledge base consists of the procedures used for the performance of the basic operations of making test readings, using technical manuals, reading schematic and wiring diagrams, and calculating using mathematical formulas.

These dependent measures were administered individually to the subjects. To control for the effects of the instruction provided at the Service Training School, the measurement instruments were administered to the novice subjects before instruction began. Following the administering of the measurement instruments, Student's *t* was calculated using SPSS^x (1986) to determine the significance of the difference between the means.

Investigation 2

Purpose

The purpose of Investigation 2 was to identify directly observable and indirectly observable differences in the technical troubleshooting performance of service technicians. For this study, troubleshooting performance included the ability to effectively acquire and interpret information and to generate, evaluate, and accept appropriate hypotheses.

Procedure

Technical preparation. Building upon the task analysis work done in Investigation 1, some additional task analysis was completed. The task analysis was used to determine what specific system faults were likely to occur in an Emerald GenSet and to select the appropriate problems for the troubleshooters to solve. Following the identification of potential system faults, specific problems had to be selected. The selection of the troubleshooting tasks was critical to the attainment of useful results and had to be determined based upon specific criteria (Evans & Smith, 1953). The following six criteria were used for the selection of the problems which were presented to the troubleshooters: (a) the problem must represent an actual live system failure, (b) it must be relatively easy to insert the failure, (c) the problem must not represent a safety hazard to the operator or a hazard to the equipment, (d) a visually detectable problem is unsuitable, (e) no intermittent failures should be presented, and (f) single failures are considered ideal (Johnson, 1980).

In addition to the practical selection criteria outlined above, the selection of the actual fault involved the selection of a representative sample from the appropriate class of problem. Four classes of troubleshooting problems were relevant (P. E. Johnson, personal communication, December 16, 1986). The four classes of troubleshooting problems are: (a) frequently occuring and easy to diagnose, (b) frequently occuring and hard to diagnose, (c) infrequently occuring and easy to diagnose, and (d) infrequently occuring and hard to diagnose.

The two classes of problems that are easy to diagnose were not expected to produce interesting results because the troubleshooters would not have a difficult time solving these. These easy problems do not require the troubleshooters to use higher level thinking processes and their deeper knowledge base. The frequently occuring but hard to diagnose problems were not investigated because they were likely to be solved by recognizing patterns within the problem. Because these problems occur frequently, the troubleshooters were expected to have a large number of patterns that have been developed through experience which could be recognized during problem solution. Because pattern recognition was likely to be the major process used, the troubleshooters would not need to invoke their deeper knowledge base. Problems that occur infrequently and are hard to diagnose were selected for this study because the unfamiliarity and difficulty of the problems require the troubleshooters to invoke cognitive processes that access a deeper level of knowledge than with the other classes of problems.

A subject matter expert from Onan Corporation Training School was used to identify problems that were representative of the fourth type of problem described above. From this list of problems (see Appendix E), two were chosen according to the critera used by Johnson (1980). One of the selected problems was a faulty fuel pump. This problem gives an initial symptom of the unit cranking but not starting. From this symptom, the troubleshooter should realize that two sub-systems, ignition or fuel, must be the most likely sources of the problem. This problem could involve either mechanical or electrical tests. The second problem selected was an open wire between the printed circuit board and the starter solenoid. The initial symptom for this problem is only a light clicking of the fuel pump. From this symptom the troubleshooter should realize that the fuse, start switch, and printed circuit board must be good because they are connected in series before the fuel pump. This problem is primarily electrical in nature.

Following the selection of the specific problems to be used in Investigation 2, a detailed cognitive task analysis was completed. Using the preliminary task analysis results, technical manuals, and subject matter experts, the cognitive task analysis provided a complete record of the problem space for the actual problems to be investigated. The problem space was mapped to provide a graphic portrayal of the possible sequences through the problem space, the events that occur as the unit is started, and the links between the events. This map was used by the investigator during the collection and analysis phases of the study to aid understanding and interpretation of the troubleshooters' performance.

Data collection. Verbal protocols were used for technical troubleshooting performance data. Subjects were instructed to "think aloud" as they worked through a problem (see Appendix F). These verbalizations were recorded using an audio cassette recorder and were later transcribed for analysis. Prior to the actual collection of the protocols, each subject was given several practice exercises to help them become comfortable with the thinking aloud process (Ericsson & Simon, 1984). Following the practice exercises, each subject was individually presented with an Emerald GenSet that was not working properly. They had available to them all the necessary equipment and materials needed to solve the problem including schematic and wiring diagrams, test equipment, and technical manuals. Two problems, which were selected according to the criteria outlined earlier, were presented to all of the subjects.

Data coding. Using the Technical Troubleshooting Model and the problem space maps as a guide, quantitative and qualitative analysis was conducted. The recorded "thinking aloud" protocols of the research subjects were transcribed (see Appendix G). The following instructions were given to the transcriber:

- Do not attempt to determine the ends of phrases.
- Begin a new line following each pause that is between 3 - 5 seconds.
- Type the word "pause" for each pause that is longer than five seconds.
- Do not place any punctuation marks in the transcription.

Following the transcription of all verbal protocols, the investigator listened to each recording to discover any errors in the transcription, to segment the protocols, and to eliminate any irrelevant verbalizations. Protocol segments consist of discrete thoughts and are determined by each short pause in the recorded protocols (Ericsson & Simon, 1984). The segmented protocols were then divided into separate episodic events. An episode was defined as one complete pass through the Technical Troubleshooting Process Model. Each episode consisted of (a) the selection of at least one potential hypothesis, (b) the acquisition of information for the purpose of evaluating the hypothesis, (c) the interpretation of the acquired information for the purpose of evaluating the hypothesis, and (d) a decision to accept or reject the hypothesis. This statement did not have to be explicitly stated. For example, following the evaluation of a hypothesis, if the subject generated a new hypothesis then the old hypothesis was considered rejected.

After dividing the segmented protocols into episodes, each segment was coded. Each code represented either a cognitive or behavioral event. The individual segments were grouped into the following code categories:

- Action (ACT) -- A deliberate, physical manipulation of the system hardware for the purpose of acquiring information (e.g. press start switch, remove spark plug, etc.).
- Acquisition of Information (ACQ) -- The acquisition of information is divided into two separate types, deliberate and incidental. Deliberate acquisition is the purposeful search for information while the incidental acquisition is

the obtaining information by accident or chance. Either type of information acquisition may be from internal or external sources and obtained for the purpose of generating or evaluating hypotheses. The "Sources for Information Acquisition" chart contains a listing of all potential information sources and was used for scoring this category.

- Desired (DES) -- The deliberate process of seeking but not obtaining information from internal or external sources for the purpose of generating or evaluating hypotheses. The "Sources of Information Acquisition" chart was also used for scoring this category.

- Interpretation (INT) -- The interpretation of information can take two forms. It may be either a verbal description (i.e. "I measured 12 volts") of the acquired information or its meaning (i.e. "12 volts should be enough to start the engine").

- Hypothesis (HYP) -- The selection of a potential fault in the system based on previously acquired and interpreted information. The hypothesis may be stated as a goal that describes what will be done next.

- Decision (DEC) -- A verbal statement denoting the acceptance or rejection of the hypothesis that is currently being evaluated. This decision may or may not be correct.

- Irrelevant (IRR) -- Protocol statements that contain ambiguous, meaningless, or irrelevant information.

A second rater was used to validate the coding process. One complete page of protocols from each subject on each problem was coded independently by both the investigator and the second rater. These pages contained 20% of the total segments generated. An interrater agreement of .88 was obtained which means that the two raters agreed on the coding of 88% of the segments.

Data analysis. Following the coding of the segmented protocols, the analysis of each of the coded categories began. Specific dependent variables in each coded category were used in the analysis. The specific micro-analysis procedures for each of the coded categories is described below:

- The Action (ACT) segments were used solely for their contextual value in interpreting the Information Acquisition segments.
- The Information Acquisition (ACQ) segments were individually analyzed to determine their information type, specificity, and relevancy of the desired information. The types of information that could be acquired were either internal or external and were found on the "Sources of Information Acquisition" chart. The specificity of information variable involved the seeking of general or specific information. Information relevancy concerned whether the information that was acquired was consistent and logical with the problem and prior information.
- Desired Information (DES) segments were counted to determine the total frequency of failed attempts to acquire information.
- The Information Interpretation (INT) segments were analyzed to determine the accuracy of the interpretation based on the previously acquired information and the amount of interpretation that is made. The information interpretation was also analyzed to determine the level of interpretation. These levels were interpretations that were primarily descriptive and those that were primarily explanatory in nature.
- The Hypothesis (HYP) segments were used to determine the total number of hypotheses that were generated, the relevancy of those hypotheses, and the selection criteria that were used to chose the hypotheses. Hypotheses could be selected based on their efficiency to eliminate other possibilities, their ease of testing, and their logicality.
- The Decision (DEC) segments were analyzed to determine the likelihood of accepting the hypothesis when it is false.

In addition to the micro-analysis, a qualitative macro analysis was conducted to reveal a global picture of the troubleshooting process. Episodes were plotted on the problem space maps for each subject. These process traces were compared and analyzed for commonalities between groups and within groups.

CHAPTER IV

Results

The data were collected within the confines of the two investigations described earlier. Investigation 1 pertained to the domain-specific knowledge that troubleshooters bring to a problem situation. This knowledge base included both declarative and procedural knowledge. Investigation 2 involved the collection of data as subjects worked through two realistic troubleshooting situations. Areas of interest included observable and non-observable troubleshooting performance. The results of the data collection phases of each investigation will be described using the major research questions as a guide. Following the description of the quantitative analysis of the differences between the experts and novices, a qualitative analysis of several troubleshooting processes will be described.

Research Question One: How does level of expertise relate to the declarative knowledge base that technical troubleshooters bring to a problem situation?

The declarative knowledge base contains the facts, principles, and concepts that an individual knows (Anderson, 1980; 1982). This definition has been operationalized for this study to include the subject's knowledge of the basic principles and mathematical formulas that are related to the domain of interest and the subject's understanding of the operation and function of the technical system that is being investigated.

The results of the Basic Principles Exam that was developed and administered to the subjects show a clear difference between the expert and novice groups. As detailed in Table 1, the t - test results for the raw mean scores for each group are significantly different ($p < .01$) for all three subscales of the exam as well as the total exam score. In addition to the differences in knowledge of basic principles, the data also show a clear difference in the subject's knowledge of the mathematical formulas that are relevant to the domain of interest (see Table 1).

TABLE 1

Raw Score Means, Standard Deviations, and *t* - Test Values for Basic Principles Exams

Exam		Group				
		Expert		Novice		
	Items	*M*	*SD*	*M*	*SD*	*t*
Mechanical	14	10.20	.84	6.60	1.14	5.69 *
Magnetic	13	10.80	1.92	7.40	1.14	3.40 *
Electrical	14	13.00	1.22	4.80	2.39	6.83 *
Total	41	34.00	2.92	18.80	3.70	7.21 *
Formulas	10	8.80	1.30	.40	.89	11.88 *

Note: $N = 5$ for each group.
df = 8.
$^{*}p < .01$.

The data that describe the subject's amount of system understanding also suggests definite differences between the expert and novice groups. These data were collected in two parts. First, an exam of 20 questions was administered to the subjects. The raw mean score on the 20 item test for the expert group was 18.0 and for the novice group was 11.8. Student's *t* indicated a significant difference between the two groups on this measure ($t(8) = 6.39, p < .01$).

Secondly, an interview was conducted with each of the subjects. This interview involved asking each subject to identify system parts, to explain their operation, what their function is, and how they are related to the entire system. These data suggest that the novices were able to identify most of the generator parts and were able to provide a description of the function and operation of the parts (see Appendix H). Their descriptions however were not in specific terms which contrast with the experts. The novices were able to talk about how switches and starters work in general while the experts talked specifically about the particular switch and starter on this type of generator. The depth of system understanding also appeared to be a major difference between the groups. When asked to describe the operation of the generator as a whole system, the novices provided scanty accounts from rote memory about the generation of electricity from a generator. In contrast, the experts delivered lengthy and detailed accounts about how a generator produces electricity. Several of the experts also went beyond the requested information and described how design modifications in the various parts and assemblies have affected the operation and efficiency of the generator.

Research Question Two: How does level of expertise relate to the procedural knowledge base that technical troubleshooters bring to a problem situation?

The procedural knowledge base contains the skills that an individual knows how to perform (Anderson, 1980; 1982). Investigating this type of knowledge involved the selection of specific skills that competent technical troubleshooters need to have. These skills included the ability to obtain information from various technical documents, to perform mathematical calculations, and to trace current flow on schematic drawings. As shown in Table 2, no difference was found in the ability of the two groups to obtain information from either the service manual or the parts manual. Both groups obtained the requested information with similar success. However, Table 2 also shows that the two groups did differ significantly in their ability to solve problems using mathematical formulas. Each subject was given ten domain-related word problems to solve without the appropriate formulas explicitly given. On this task the novice subjects were able to solve only 34% of the problems while the expert subjects were able to solve 96% of the problems. Even after the novices were given the appropriate formulas to use they were only able to solve 62% of the problems.

TABLE 2

Raw Score Means, Standard Deviations, and *t* - Test Values for Procedural Knowledge Measures

Exam		Group				
		Expert		Novice		
	Items	*M*	*SD*	*M*	*SD*	*t*
Service Manual	6	5.20	1.29	4.75	2.28	1.29
Parts Manual	9	8.80	2.19	7.60	1.14	2.19
Calculations	14	9.60	5.40	3.40	2.51	5.40 *

Note: N = 5 subjects in each group.
df = 8
$^{*}p < .01$.

Technical troubleshooters often need to trace current flow on schematic drawings as they attempt to find problem faults within a system. This ability involves both the declarative and procedural knowledge bases.

Subjects must understand the function and operation of the individual parts within the system and their relation to the system as a whole. They must also be able to differentiate between the various types of circuits within the schematic drawing itself. To measure for this ability, each subject was given a schematic drawing of the BGE GenSet (see Appendix C) and was asked to trace, in different colors, the circuits that carry battery current, ground, and alternating current (AC) while the unit is running. The data show a clear difference between the groups on their ability to accurately trace the various circuits on the schematic drawing (see Table 3).

TABLE 3

Raw Score Means, Standard Deviations, and t Test Values for Missing Lines of Circuit Tracing Measure

	Group				
Exam	Expert		Novice		
	M	*SD*	*M*	*SD*	*t*
Battery	3.40	3.85	13.80	7.16	-2.86 *
Ground	1.80	1.30	10.00	6.44	-2.79 *
Alternating Current	.80	.84	12.00	3.46	-7.03 **
Total	6.00	4.47	36.20	15.61	-4.16 **

Note: *N* = 5 subjects in each group.
df = 8.
$^*p < .05$. $^{**}p < .01$.

Of the lines that were drawn, the experts were significantly more likely to have drawn them in the correct places. This fact held true for all three types of current carrying circuits. For lines that were drawn incorrectly, no significant difference was found between the two groups. For the battery, ground, and AC carrying circuits together, experts drew an average of 1.2 incorrect lines while the novices drew 4.8 incorrect lines for a non-significant $t(8) = -1.26, p > .05$.

Research Question Three: How does level of expertise relate to technical troubleshooting performance?

Observable performance. Technical troubleshooting performance has been divided into both directly observable performance and indirectly observable performance. The directly observable performance data include the variables of success rates, time to solution, and procedural skill performance. Each subject was given two BGE GenSets that were not operating properly. Their task was to find the fault using the various resources that were available. All of the experts were able to find the faults in both units. The experts proceeded in a straight forward manner with the exception of two of the experts on the wire problem. When these two subjects read a high voltage (60 volts) off the fuel pump, they interpreted that reading as inappropriate and spent time searching for the source of that voltage rather than for the original problem fault. After realizing that the high voltage was not related to the original problem these two experts generated a new set of hypotheses and promptly solved it. The novices were not as successful in finding faults. Only three of the five novices were able to find the fault in the fuel pump problem while only two were able to find the fault in the wire problem. The novices were allowed to continue searching for the fault until they felt it was useless for them to continue or until a 45 minute time limit had been reached. In only one of the five unsuccessful attempts was the time limit reached.

The time to solution data shows that problem type is an important factor in the performance of technical troubleshooters. On the fuel pump problem, the novices actually solved the problem faster than the experts. Part of the slower performance by the experts on this problem can be explained by the observation that two of the experts spent considerable time searching for what they perceived as a design flaw in the system. The experts averaged 11.4 minutes (*SD* = 5.86) to solution while the novices who solved the problem averaged 6.3 minutes (*SD* = 3.79). On the wire problem, the experts were able to solve the problem almost five times faster than the novices. The experts had a mean time of 7.2 minutes (*SD* = 4.09) while the novices who solved the problem averaged 33.5 minutes (*SD* = 16.26).

The final directly observable performance variable is the procedural skill of the subjects. This variable concerns the ability of the subjects to accurately perform various procedural measures. These measures include both mechanical and electrical procedural tests. Of the various methods for acquiring information, the experts were more likely to rely on test procedures than the novices. On the fuel pump problem, both groups divided the test procedures evenly between mechanical tests and electrical tests. From the total number of test procedures made, 55.8% were electrical for the experts and 47.3% were electrical for the novices. Both groups were able to successfully perform all of the test procedures they attempted. On the wire problem, which is an electrical problem, all of the test procedures made by the expert group were electrically oriented. Of the test procedures made by the novices, 87.8% were electrical. All of the subjects were able to accurately perform the test procedures on this problem with the exception of one novice who made three faulty electrical tests out of a total of 19.

Indirectly observable performance. The indirectly observable performance data includes the information acquisition, information interpretation, hypothesis generation, and hypothesis acceptance variables. Through the use of the coded protocol segments, it was possible to conduct both a quantitative and qualitative analysis of the data.

Information Acquisition

The information acquisition segments were analyzed to determine the types of information sought, the nature and relevancy of the information, and the success of the subjects to obtain desired information.

The types of information sought. Figure 4 provides a graphic representation of the types of information sought by the two groups of subjects. From these data it is clear that on both types of problems the experts sought information by technical evaluation means more than the novices. Novices sought information by sensory means more than the experts. The data show little or no apparent difference between the groups in the search for information in the job aids and technical support categories.

The nature of information sought. In Figure 5 it can be seen that the experts sought specific information while the novices looked for more general information. These data hold true on both problems although a greater difference was found on the wire problem. Of the information the experts sought on the fuel pump problem, 81.8% was specific while the novices sought 73.3% specific information. On the wire problem the experts sought 81.0% specific information while the novices sought 62.9% specific information.

The relevancy of information sought. For the relevancy of information variable it was found that the type of problem influenced the groups (see Figure 6). On the fuel pump problem, over 90% of the information sought by both groups was relevant. However, on the wire problem, which was a harder problem for the novices, the experts sought 97.6% relevant information while the novices sought only 61.4% relevant information.

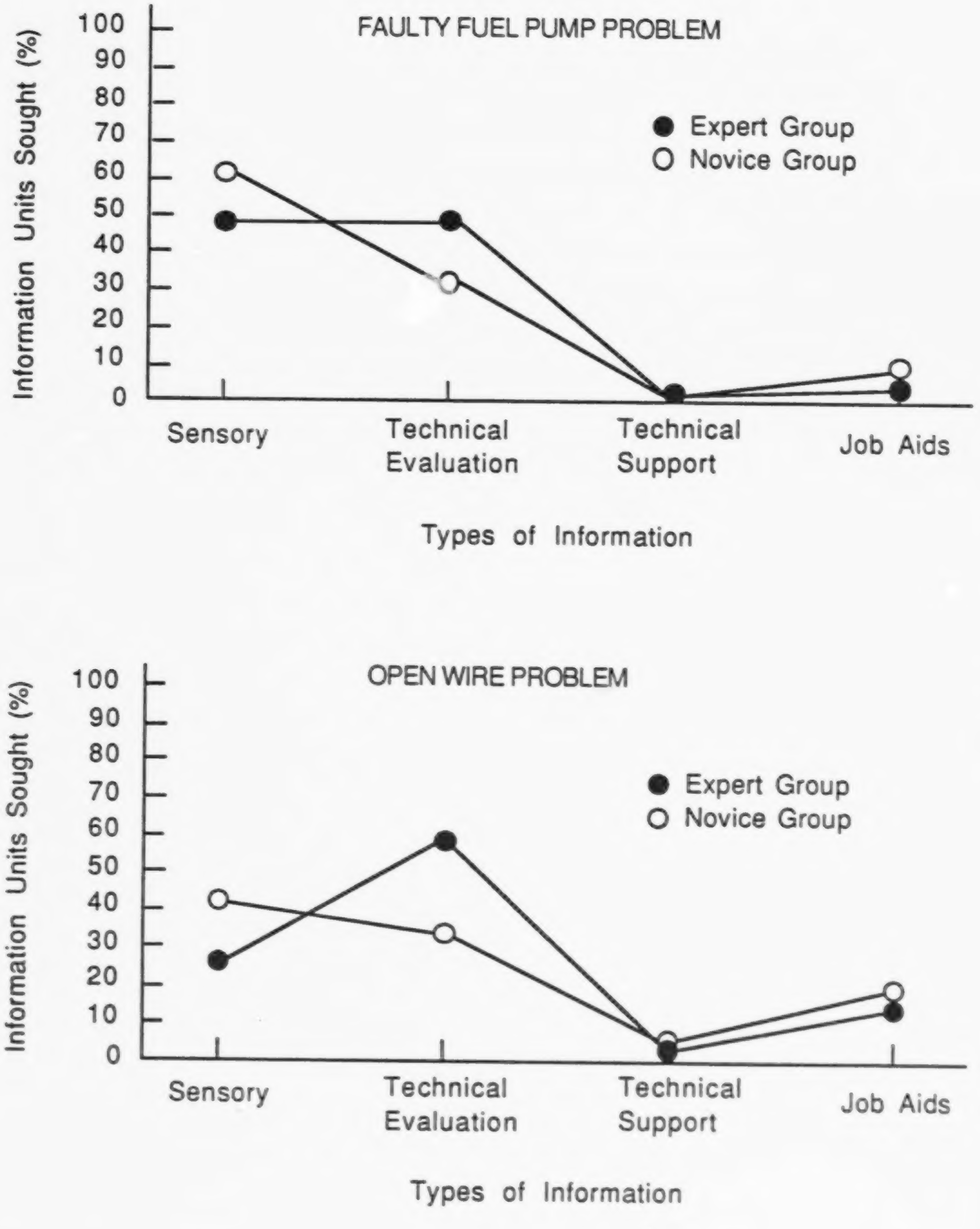


Figure 4. Types of information sought during troubleshooting.

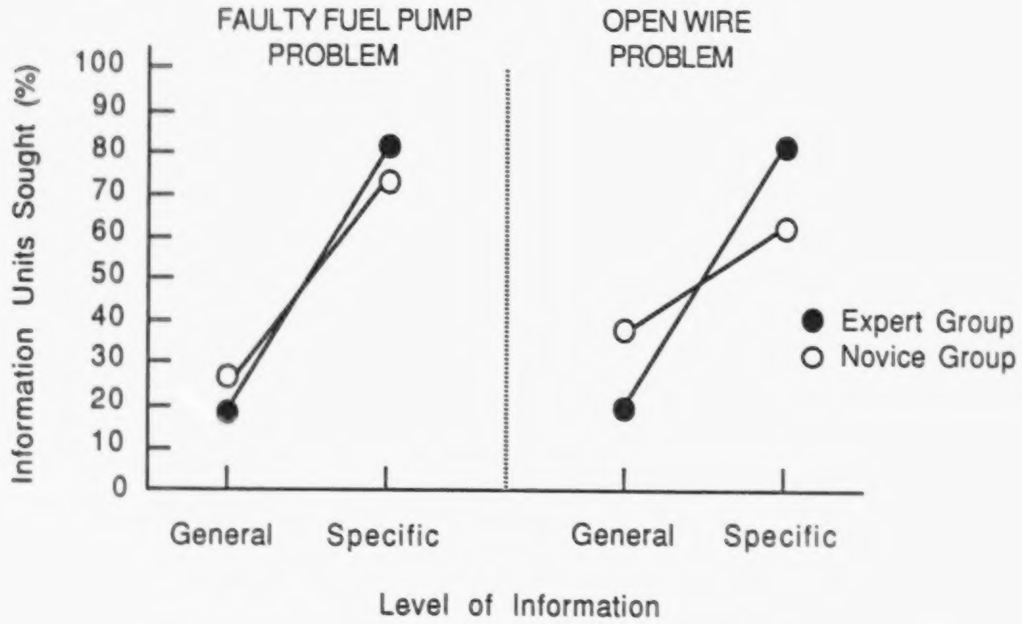


Figure 5. Level of Information Specificity

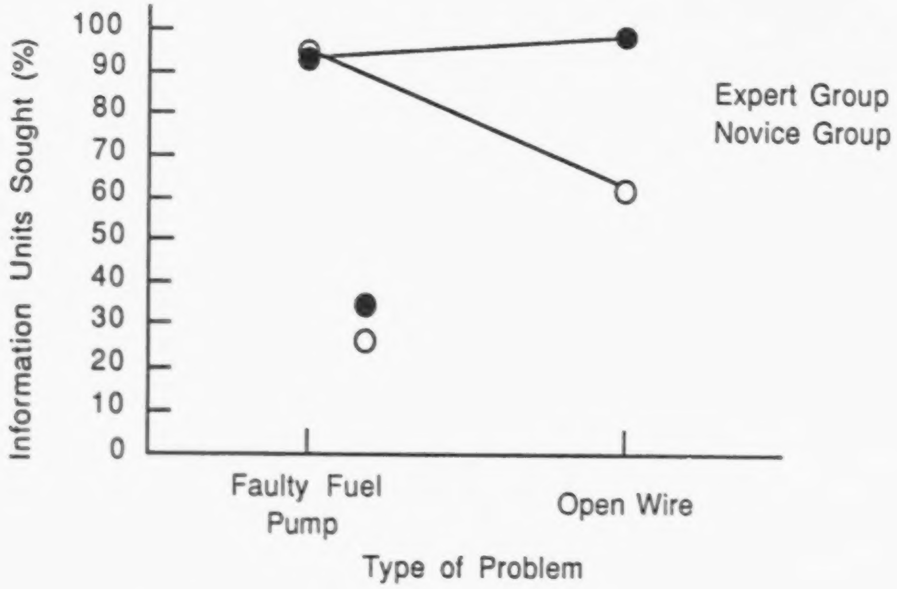


Figure 6. Relevancy of Information Sought During Troubleshooting.

The effectiveness in obtaining information. Once again the type of problem was found to influence the information acquisition process. As shown in Figure 7, it was found that the groups differed slightly on the fuel pump problem but greatly differed on the wire problem. On the fuel pump problem both groups were able to obtain over 90% of the information they sought. This was not the case on the wire problem where the experts obtained 100% of the information they sought while the novices could only obtain 73.6% of the desired information. Of the information that the novices could not obtain on the wire problem, 48.6% was from job aids (18 information units), 37.8% was sensory information (14 information units), and 13.5% was from technical evaluations (5 information units).

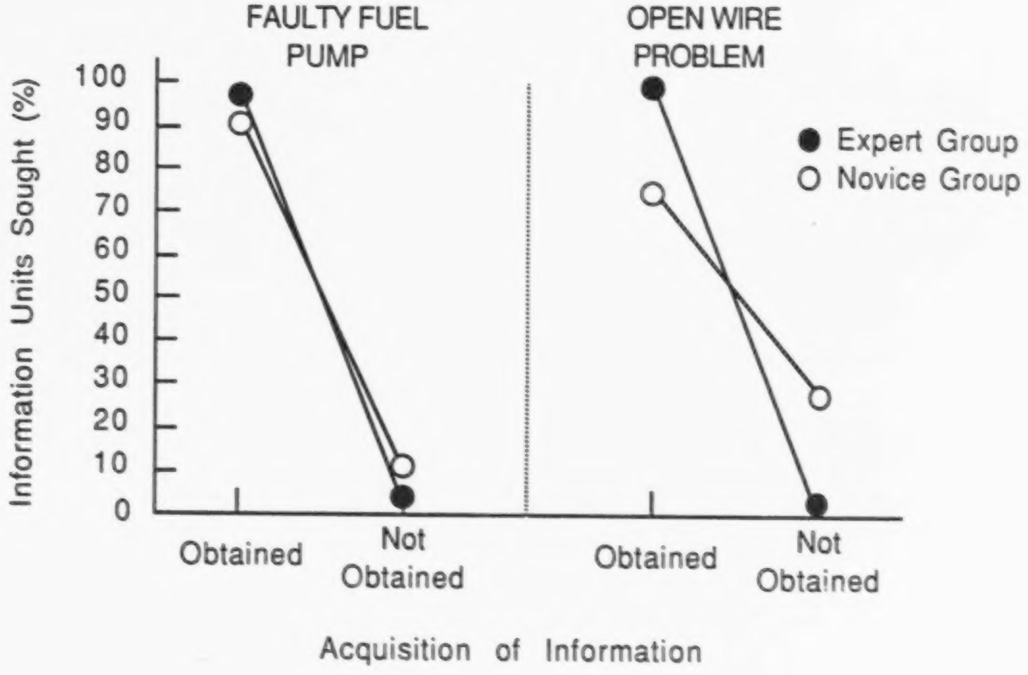


Figure 7. Effectiveness in Obtaining Information.

Information Interpretation

Following its acquisition, the information must be interpreted by the subjects. The information interpretation variables include the level of interpretation and the accuracy. Information can be interpreted at two levels; description and meaning. Of the verbal interpretations that appeared in the subject protocols, both groups had more descriptive than meaningful interpretations. However, the data do not provide a clear picture of the differences in the group's information interpretations (see Figure 8).

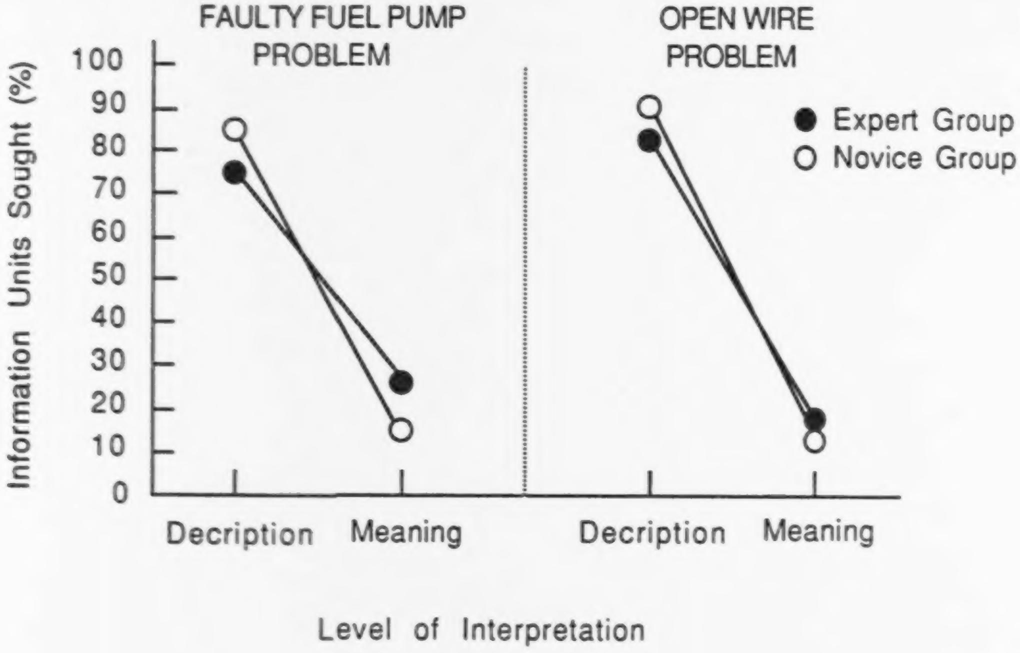


Figure 8. Level of Interpretation of Acquired Information.

On the one hand, the novices produced slightly more descriptive interpretations than the experts. On the fuel pump problem, the experts had 75.9% descriptive interpretations while the novices had 84.1%. On the wire problem, the experts had 81.4% descriptive interpretations while the novices had 89.1%. On the other hand, the experts provided more interpretations of the meaning of the information than the novices. Of the verbal interpretations that were made by the experts, 24.1% were meaningful interpretations on the fuel pump problem and 18.6% were meaningful on the wire problem. The novices generated 15.9% and 10.9% meaningful interpretations, respectively.

The other variable of interest in this section is the accuracy of the interpretations. As in the level of interpretation data, little difference was found in the ability of the groups to interpret information. The experts accurately interpreted 99% of the information on the fuel pump problem and 98% on the wire problem. The novices accurately interpreted 98% of the information on the fuel pump problem and 93% on the wire problem.

Hypothesis Generation

Following the acquisition and interpretation of information, the Technical Troubleshooting Model shows that troubleshooters generate one or more potential faults or hypotheses. More hypotheses are generated until a correct one is obtained. The variables of interest for the hypothesis generation phase of the troubleshooting process include the total number of hypotheses generated, the relevancy of the hypotheses, and the hypothesis selection criteria that are used. The coded protocol statements provide the data needed to examine differences between the two groups of subjects.

The number of hypotheses generated. Once again the type of problem seemed to affect the performance of technical troubleshooters. As shown in Figure 9, the groups did not differ on the fuel pump problem but greatly differed on the wire problem. On the fuel pump problem, both groups generated 29 hypotheses. The experts generated 24 hypotheses while the novices generated 61 hypotheses on the wire problem.

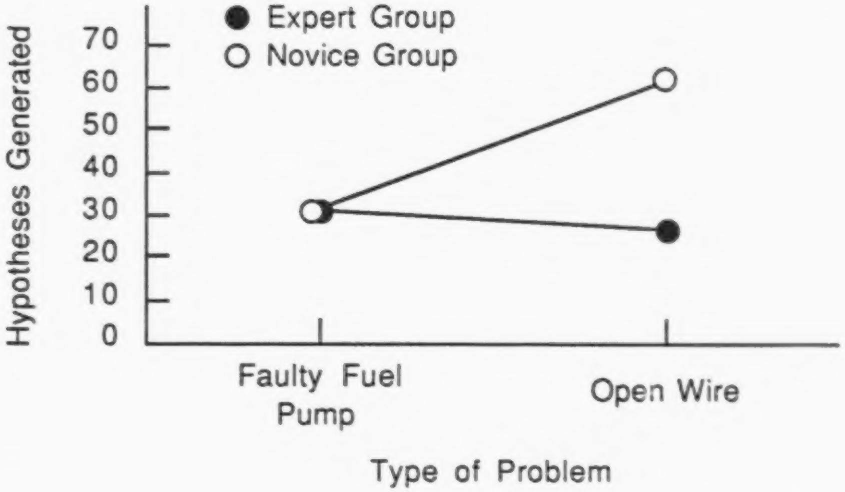


Figure 9. The Number of Hypotheses Generated.

The relevancy of hypotheses generated. As was found on the data for the total number of hypotheses generated, the groups differed slightly on the relevancy of the hypotheses generated on one type of problem while they differed greatly on the other (see Figure 10). On the fuel pump problem, both groups generated primarily relevant hypotheses. The expert group generated 96.6% relevant hypotheses and the novice group had 86.2% that were relevant. On the wire problem, the experts generated 91.7% relevant hypotheses while the novices generated only 41.0% relevant hypotheses.

Using the problem space maps to graphically represent the subjects' selection of relevant hypotheses, it is clear that the type of problem greatly influenced the results. The scatter graph in Figure 11 shows the hypotheses that were generated by both groups on the fuel pump problem. Each circle represents one hypothesis that was generated and evaluated by a subject and the placement on the problem space map provides a clue as to the nature of the hypothesis. The lightly shaded areas of the map represent

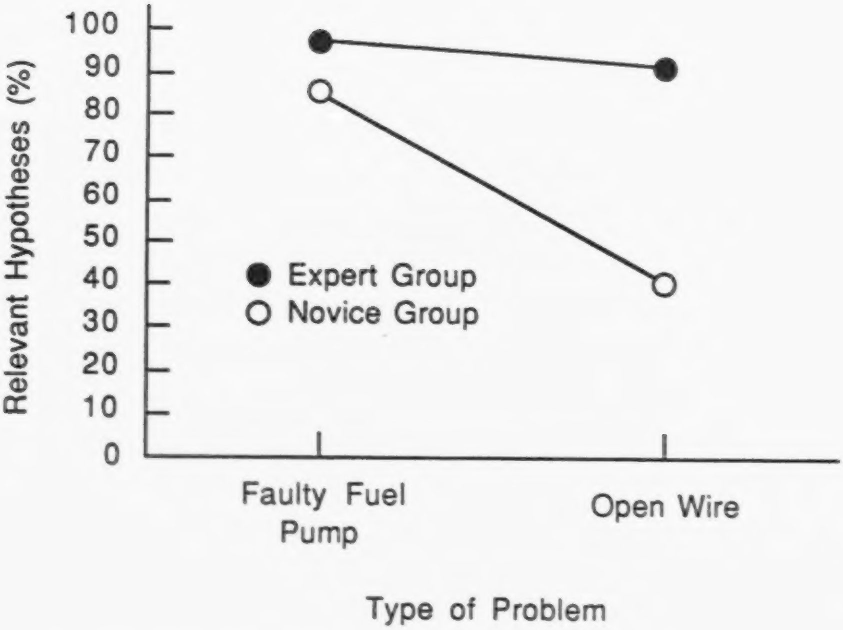


Figure 10. The Relevancy of Hypotheses Generated.

the actual problem space for this problem based on the initial symptoms of the generator. As shown in Figure 11 it is clear that both groups confined the majority of their hypotheses to the problem space. With the exception of the three faulty fuse hypotheses and the one oil fault hypothesis, the novices were able to keep their hypotheses within the problem space. From the problem space map, it appears that the experts generated two irrelevant hypotheses. However, on closer examination of the protocols, one hypothesis was generated as standard operating procedure. For the oil fault hypothesis, the expert stated in the protocol that this was not the problem, but he would check it anyway. The other irrelevant hypothesis, a bad board fault, was generated by an expert although he did not actually test it. The expert was led to the board by a high voltage reading to the fuel pump which seemed abnormal to the expert. Immediately after he generated the irrelevant hypothesis, he realized that there was a more

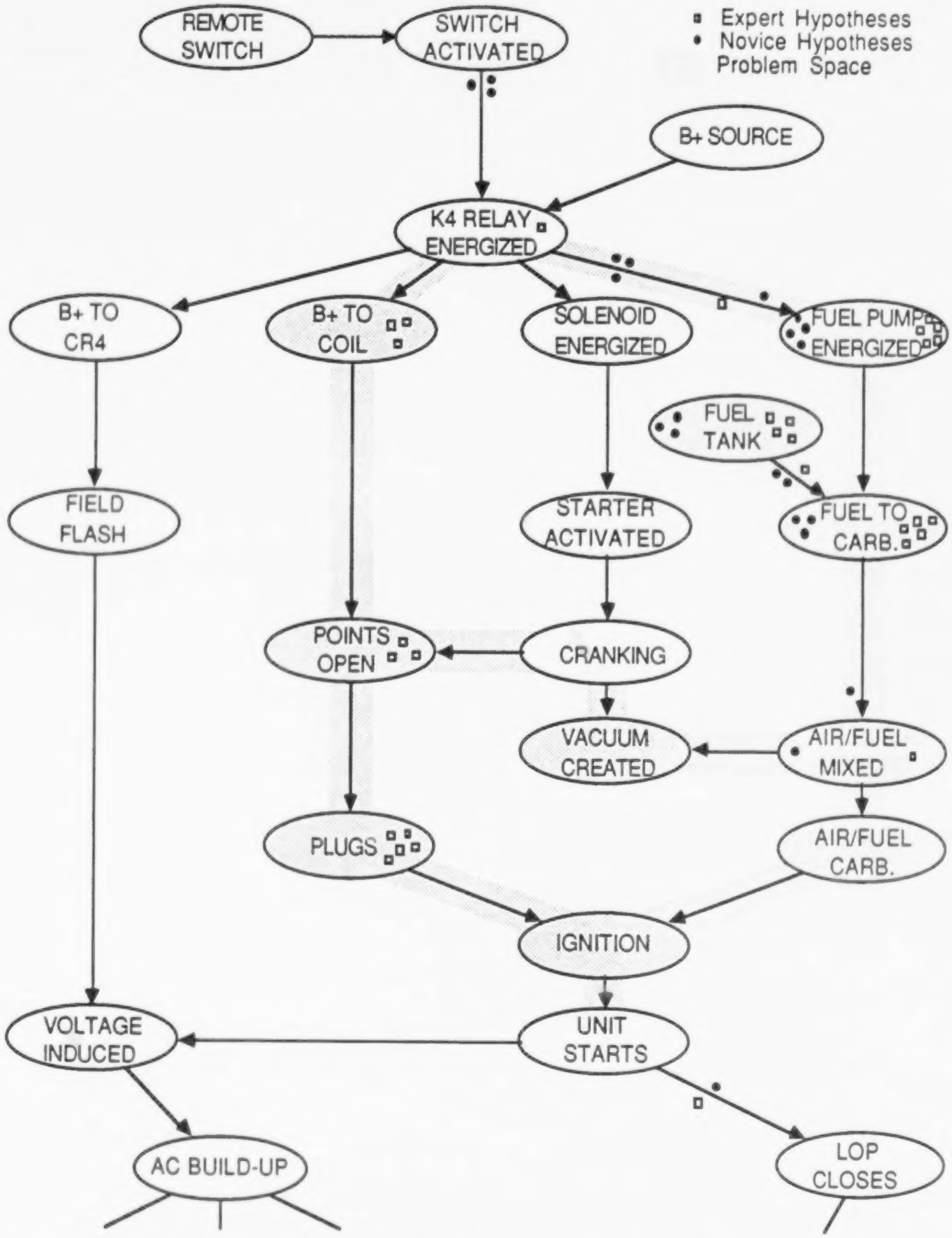
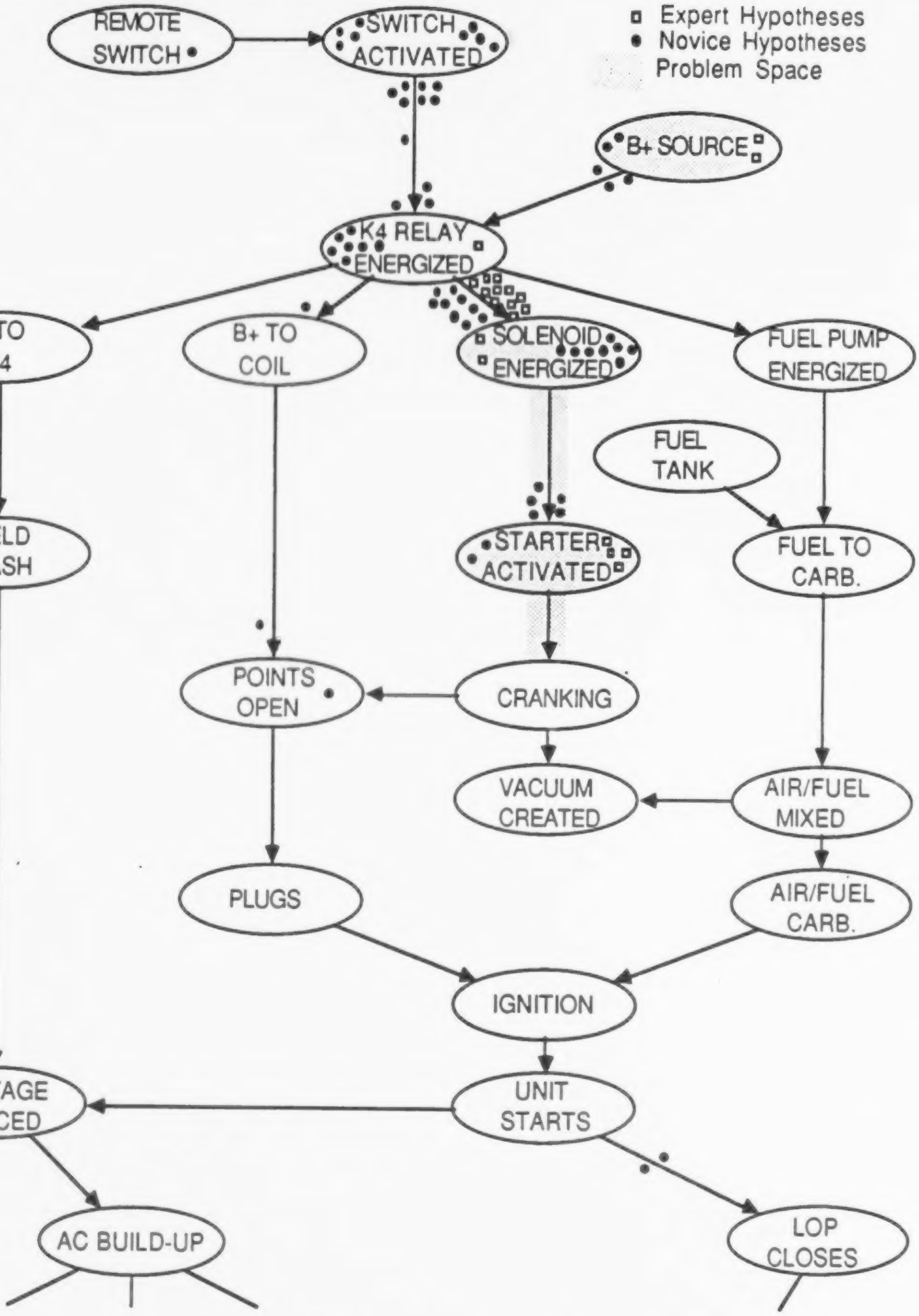

▫ Expert Hypotheses
• Novice Hypotheses
Problem Space
REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

Figure 11. Group Problem Space Map for Fuel Pump Problem.

appropriate test that could be made to identify the fault and pursued that line of reasoning.

On the wire problem, a more definite difference was found in the scatter graph. Figure 12 shows the problem space for the wire problem (shaded portion) and the expert and novice hypotheses that were generated. The experts generated only two irrelevant hypotheses out of a total of 24 while the novices generated 36 irrelevant hypotheses out of a total of 61. Most of the irrelvant hypotheses generated by the novices can be grouped into three categories; faulty switch, faulty fuse, or faulty printed circuit board. All of these selections could not possibly be the fault because, in the original symptom of the problem, the fuel pump clicked which was a sign of it being energized. In order for the fuel pump to be energized, the fuse, switch, and printed circuit board must be functioning properly. The novices either misinterpreted the fuel pump clicking cue or did not understand the relation of the fuel pump to the fuse, switch, and printed circuit board.

The hypothesis selection criteria. Hypotheses are generated based upon the information that has been acquired and interpreted. The subjects appear to use specific criteria to guide their selection of the generated hypotheses. The three selection criteria that are believed to be used by the subjects are the efficiency, ease, and logicality of the hypothesis. Efficient hypotheses are those that will eliminate the greatest number of other potential hypotheses (i.e. testing for a spark problem can eliminate the points and coil because they must be in working condition for the spark to occur). The selection of the hypothesis that the coil is bad would not be efficient because, if tests show that the coil is not the problem, the spark plug hypothesis cannot be eliminated. Hypotheses are also selected based on their ease of testing. Some hypotheses may be difficult to test because of complicated or messy test procedures while others can be tested by very simple procedures. Logical hypotheses are those that could possibly be true based upon the information that is acquired and the symptoms the technical system displays.



□ Expert Hypotheses
● Novice Hypotheses
Problem Space
REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

Figure 12. Group Problem Space Map for Wire Problem.

Figure 13 shows a graphic representation of the hypothesis selection data. In the fuel pump problem the experts selected hypotheses that were efficient and logical only slightly more than the novices while the novices selected hypotheses that were easy to test only slightly more than the experts. A slight difference between the groups was also found on the wire problem for the ease variable. Of particular interest in this wire problem is the fact that the data show a great difference in the ability of the groups to select efficient and logical hypotheses. 66.7% of the expert's hypotheses were efficient selections and 91.7% were logical choices. Of the hypotheses the novices selected only 16.4% were efficient choices and 45.9% were logical.

Hypothesis Acceptance

The Technical Troubleshooting Model shows that troubleshooters make decisions to accept or reject hypotheses that have been generated. This decision is based on information that is acquired and interpreted in the hypothesis evaluation phase of technical troubleshooting. On the fuel pump problem, none of the subjects made incorrect decisions. They were all able to either accept their hypothesis as correct or generate new hypotheses based on their newly acquired information.

Experts were also able to make correct decisions on the wire problem while the novices displayed some difficulty. Four of the five novices made incorrect decisions on the wire problem. Of the hypotheses that were generated by the novices on this problem, 16.4% were incorrectly accepted. A deeper analysis of the data shows that four of the hypotheses were accepted because the subjects had no way to accurately test them. Five hypotheses were accepted based on misinterpretations. One hypothesis was accepted simply because the subject was unable to recall data from earlier tests. All ten of these incorrectly accepted hypotheses resulted in the replacement of new parts. It appears that it was easier, though costlier, to replace the suspected part with a new part rather than devise a

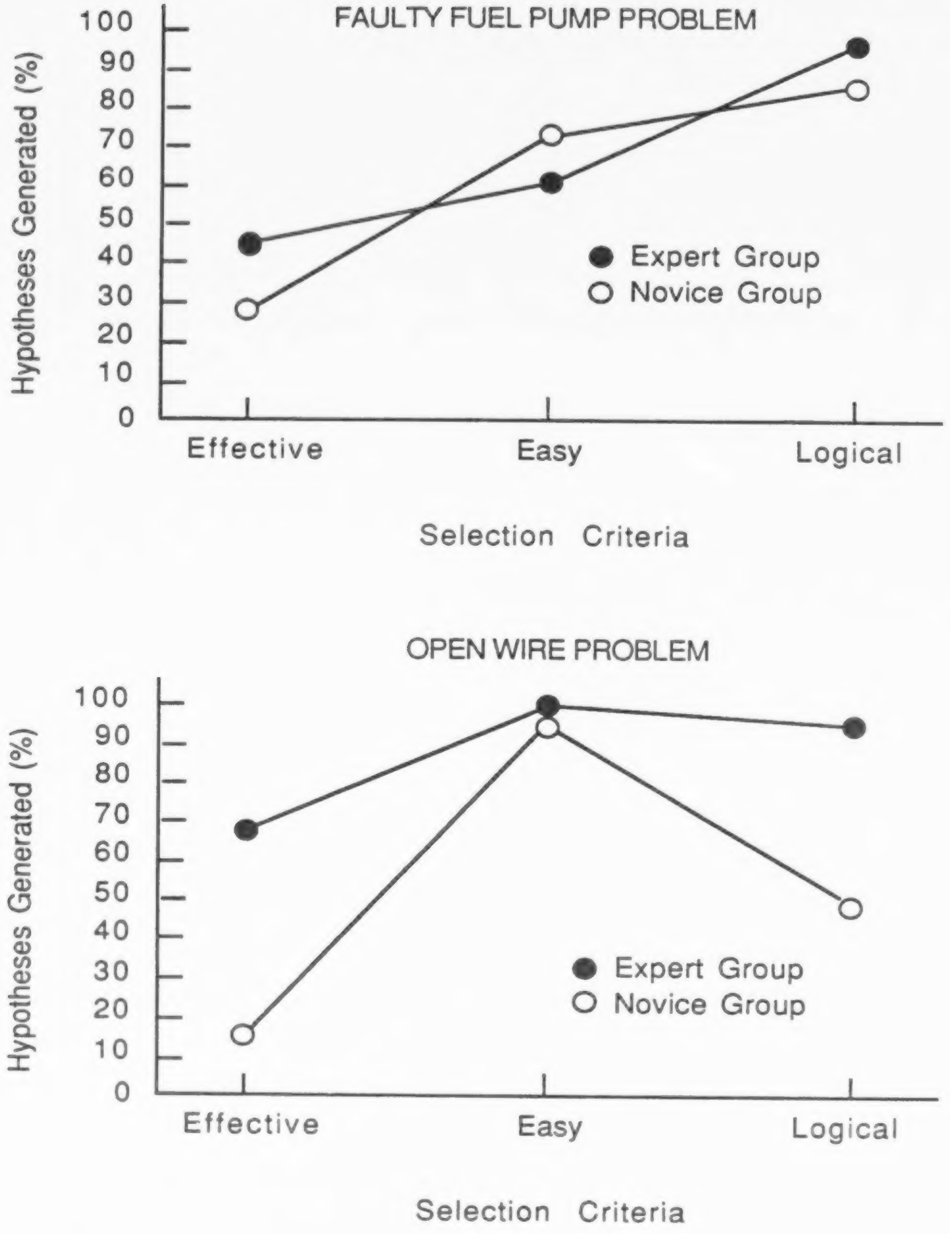


Figure 13. Hypotheses Selected According to Three Criteria.

better test or re-evaluate a decision.

Qualitative Analysis

The above quantitative analysis of the cognitive processes of the experts and novices clearly shows definite differences between the groups. Beyond the quantitative description of these processes it is valuable to analyze the troubleshooting protocols qualitatively. This qualitiative analysis provides a clearer understanding of the troubleshooting activities of the experts and novices. The four major types of information that have been qualitatively analyzed are the subjects' initial problem formulation, the development of the problem space representation, an examination of the subjects' sequence through the problem space, and an identification of patterns within the protocol episodes.

Problem formulation. One of the first steps in the problem solving process is the initial problem formulation. Problem formulation involves understanding the problem through the development of the problem space. As described in the literature review, the development of the problem space involves the identification of the initial conditions that exist at the start of a problem. If an accurate understanding of the initial conditions is gained, the problem solver will be able to make better moves through the problem space. In this technical troubleshooting problem, the subjects varied in the amount of information they were able to gather regarding the initial state of the problem. The data suggest that the expert troubleshooters were able to gain more information at the start of the problem than were the novices. The protocols show a definite contrast in the amount of information gathered by the two groups. Following an initial attempt to start the generator, Expert 1 states:

> "I can feel the fuel pump pumping so I know that I do have voltage to my fuel pump. Therefore, that means my circuit board is good, am applying voltage, ... at this time I know that the fuse is good, and it gives me a pretty good indication that I do have battery power. At this time I don't know if it's enough

> because of the fact that the fuel pump draws less current than the starter does."

From the initial symptom of the fuel pump clicking on the wire problem, this expert was able to determine that there was battery power going to the printed circuit board and the fuel pump and that the fuse and battery were likely in working condition. Contrast the above protocol segments with those of Novice 1:

> "We'll push the start button. Ah. I get nothing. Um. I'm just gonna kind of look around, take a look at it for a minute."

The other novices, as can be seen in Appendix I, also did not verbalize any of the initial conditions. As Novice 1 did, they attempted to start the unit, discovered it would not start, and then began checking various parts of the generator for problems. This lack of a clear determination of the initial conditions and their implications for the rest of the system seemed to prevent the novices from selecting an appropriate plan of troubleshooting strategies.

Problem space representation. Judging by the appearance of the problem behavior maps (see Figure 11, Figure 12, & Appendix I), all the experts were able to represent the problem space accurately based on the initial problem symptoms. Of all the troubleshooting moves made by the experts, the majority of them were located within the confines of the true problem space. After the subjects acquired the initial problem symptoms they constructed an initial representation. The expert subjects then used each hypothesis that was generated to successively reduce the size of the initial problem space. This reduction in problem space size allowed the troubleshooters to focus in on the system fault. After reviewing the problem behavior maps of the novice subjects it appears that they were able to represent the problem space accurately only on the fuel pump problem. On the wire problem the novices generated numerous hypotheses that were outside the true problem space. The lack of an accurate problem space

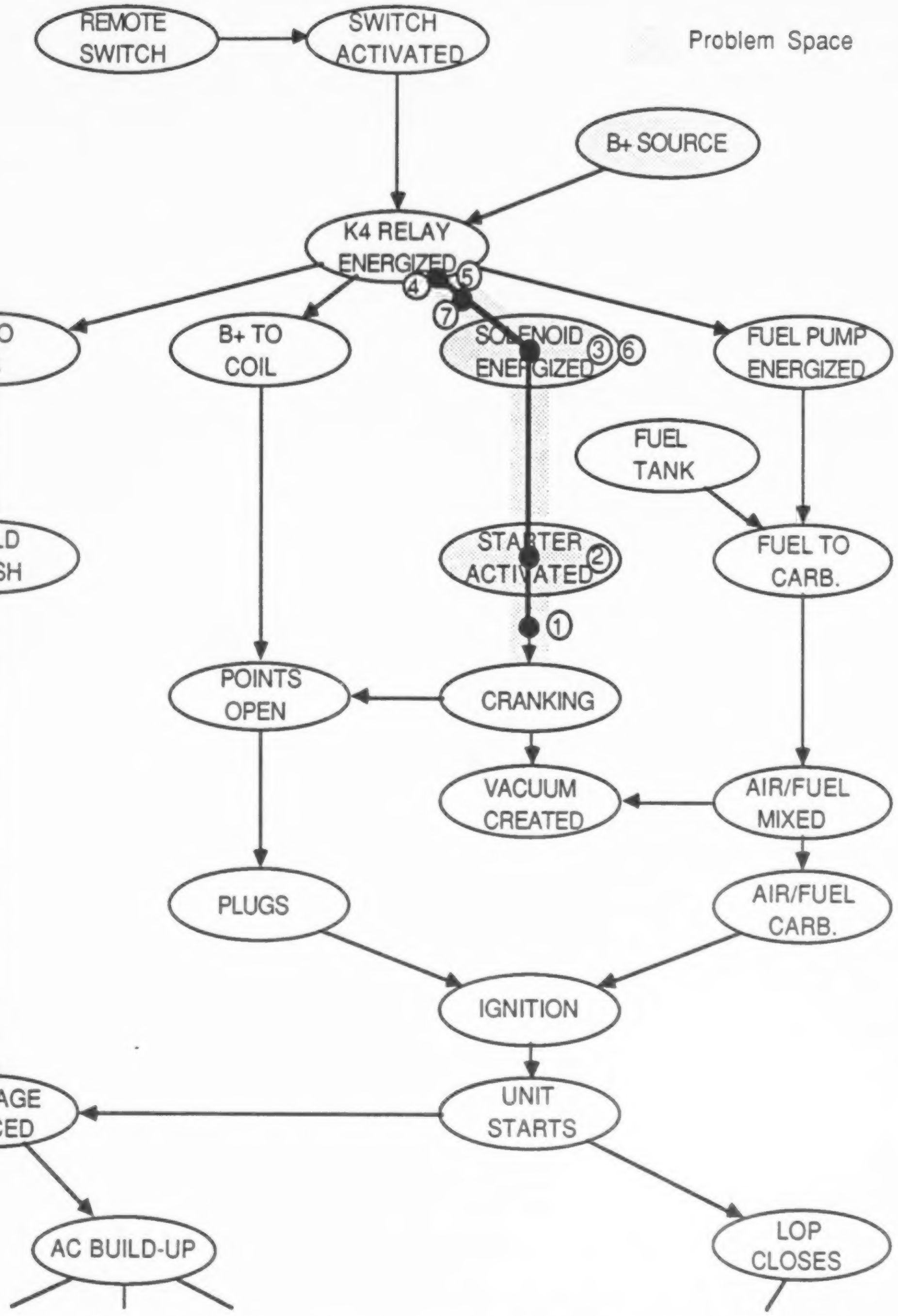

Problem Space
REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES
①
②
③
④
⑤
⑥
⑦

Figure 14. Expert 1 Problem Behavior Map for Wire Problem.

representation forced the novices to use the more random trial and error approach rather than using one of the three search techniques that are used by troubleshooters (Rasmussen & Jensen, 1974).

Problem solution sequence. A clear difference in the subjects' sequence through the problem space can be shown by a graphic representation. Figure 14 depicts the sequence of hypothesis selection on the problem behavior map of Expert 1 on the wire problem.

After acquiring the initial symptoms of the problem, Expert 1 used a functional search technique to direct him to the sub-system that most likely contained the fault. An excerpt from Expert 1's protocol shows clear evidence of his use of the functional search technique (see Figure 15).

(1) "Well, I've hit the start switch,"

(2) "I can feel the fuel pump pumping so I know that I do have voltage to my fuel pump."

(3) "Therefore, that means my circuit board is good, am applying voltage, so what I'm gonna do next is see if I have it at the starter."

(4) "I, in case there's a dead sh, short somewheres."

(5) "Ok, like I said previously, I've hit the start switch, I can hear the fuel pump pumping, I've got my hand on there, I can feel it vibrating, so"

(6) "at this time I know, least to that, that means the fuse is good, and it gives me a pretty good indication that I do have battery power."

(7) "At this time don't know if it's adequate enough, because of the fact that the fuel pump draws less current than the starter does."

(8) "So what I'm going to do next is move over to my starter terminal itself."

Figure 15. Expert 1 Protocol Excerpt from Wire Problem.

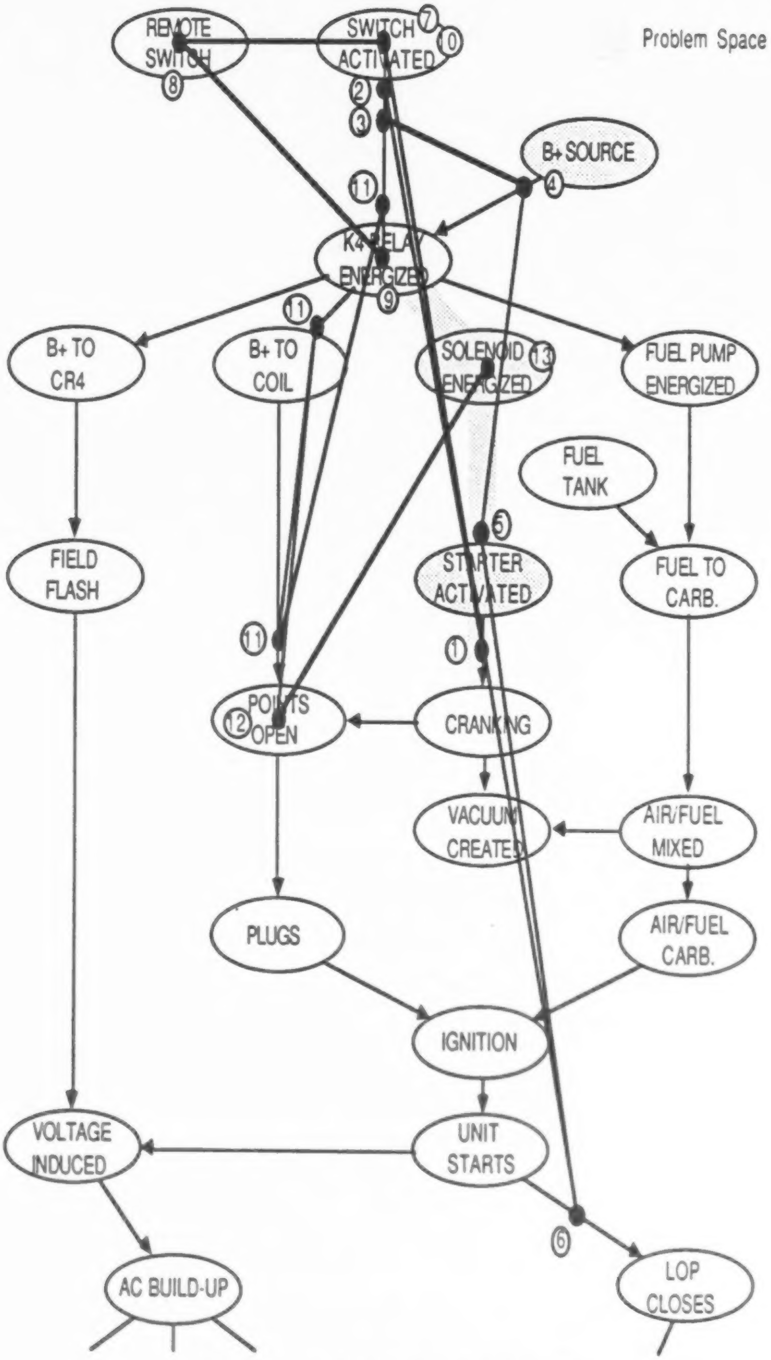

Problem Space
REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES
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Figure 16. Novice 1 Problem Behavior Map for Wire Problem.

Following this part of the protocol, Expert 1 then proceeded with a topographical search in a logical and efficient sequence through the problem space until the problem was reduced to only one possible fault.

The novices proceeded through the problem space in a completely different manner. As is shown in Figure 16, which is the sequence through the problem space by Novice 1 on the wire problem, a seemingly random pattern appears. The novice gathered an enormous amount of data which was typically irrelevant to the problem. Because of the irrelevancy of the information that was gathered, the novice was unable to use it to reduce the size of the problem space and therefore could not focus in on the fault.

Little evidence was shown to suggest that this novice was able to effectively use a functional search technique. As shown in Figure 17, he apparently attempted to use this technique but was unsuccessful.

(22) "Let's see."

(23) "Um"

(24) "Still lookin. I'm confused already."

(25) "Push the start button again."

(26) "I'm gonna listen for a while try to figure out maybe exactly where the sound's comming from."

(27) "Um"

(28) "I'm not sure."

Figure 17. Novice 1 Protocol Excerpt from Wire Problem.

This novice had difficulty even determining what the inital symptoms were which helps explain some of his random behavior. After acquiring the initial symptoms, rather than use the topographical technique as the experts did, this novice proceeded to jump around, both within and outside the true problem space, in an attempt to acquire further clues to the location of the fault. All of the experts exhibited similar efficient and logical behavior while all of the novices appeared to employ the more random approach. For a collection of all the subjects' sequences through each problem see Appendix I.

Patterns within episodes. As described earlier, an episode constitutes one complete path through the Technical Troubleshooting Model. This pass involves the acquisition and interpretation of information, the generation of one or more hypotheses, the evaluation of one hypothesis through the acquisition and interpretation of more information, and the acceptance or rejection of the evaluated hypotheses. Each segmented protocol was divided into episodes and then each segment was coded according to the scoring criteria described earlier. No pattern differences were found in the protocol analysis of the episodes. Each episode contained the information acquisition and interpretation segments that provided evidence of the evaluation of the current hypothesis. This pattern was consistent in both the expert and novice protocols on both problems. The main difference between the groups within the episodes seemed to be the quality of the hypotheses and the selection of appropriate evaluation procedures.

CHAPTER V

Summary and Discussion

Summary

The major purpose of this study was to identify the knowledge, skill, and cognitive process differences between expert and novice technicians on technical troubleshooting tasks. The identification of these differences was conducted through two investigations. Investigation 1 sought to describe the differences in the declarative and procedural knowledge bases that expert and novice troubleshooters bring to a problem situation. This phase of the study involved the development and administration of dependent measures to quantify the differences between the two groups. Investigation 2 sought to identify the differences in the troubleshooting performance of experts and novices. Subjects were presented with two generator sets that had selected faults installed in them. Each subject was asked to find the fault using any of the tools and materials that were available. In addition, the subjects were asked to "think aloud" so their verbalizations could be recorded for later analysis.

As described in the results chapter, very definite differences were found between the two groups. The expert/novice differences that were identified in this study are summarized below.

Declarative knowledge differences.

The experts knew significantly more about the principles, concepts, and theories within the domain than did the novices.

The experts knew significantly more domain relevant mathematical formulas than did the novices.

The experts had a significantly better understanding of the function and operation of the technical system than did the novices.

Procedural knowledge differences.

No difference was found in the ability of the two groups to obtain information from technical documents.

The novices had considerably more difficulty than the experts in tracing electrical circuits on schematic drawings.

The experts were significantly better at solving technical word problems using formulas than were the novices.

Directly observable troubleshooting performance.

The novices solved the fuel pump problem nearly twice as fast as the experts.

The experts solved the wire problem five times faster than the novices.

The experts were slightly more likely to use electrical test procedures than mechanical test procedures.

No difference was found in ability to perform test procedures.

Indirectly observable troubleshooting performance.

The experts sought information by technical evaluation means more than the novices.

The novices sought information by sensory means more than the experts.

No difference was found in the seeking of information through technical support or job aids.

The experts sought more specific information while the novices sought more general information.

The novices were less able to select and obtain specific and relevant information on the wire problem than on the fuel pump problem.

No difference was found in the accuracy of information interpretation.

The novices generated more hypotheses than did the experts.

The expert hypotheses were more relevant, logical, and efficient than were the novice hypotheses.

Both groups sought hypotheses that were easy to test.

The novices displayed some difficulty in making correct decisions to accept or reject hypotheses.

The experts obtained more information from the initial problem symptoms than did the novices.

The experts were better able to develop accurate problem space representations and select information and hypotheses that were within the bounds of that space.

The experts selected hypotheses that brought them closer to the fault while the novices appeared to generate hypotheses on a random basis.

The experts used search techniques that effectively reduced the size of the problem space.

No difference was found in the segment patterns within episodes in the subjects' protocols.

Discussion

After reviewing the results of this study it appears that the primary difference between the troubleshooting performance of experts and novices is that the experts were able to select better information and generate better hypotheses. There appears to be little or no difference in the ability of the troubleshooters to acquire and interpret most types of information, to perform procedural tests, or to generate and evaluate hypotheses. The major difference is in the types of information acquired, the types of procedural tests performed, and the types of hypotheses generated. So the important question is: Why are experts able to make better selections? A final review of the findings of this study should provide an answer to this question.

While other factors are likely involved, it appears that two major reasons for the experts' superior selection skills are because of the amount of knowledge experts have and the organization of that knowledge that has been developed through years of experience. Through the organization of their knowledge base, the experts were able to efficiently access their knowledge and match the information cues they observed with those in their knowledge base. This ability to recognize patterns from past experience allowed the experts to quickly make the right decisions regarding the types of information to acquire and the types of hypotheses to generate. The experts were able to acquire and interpret the initial symptoms of the problem. From this initial information, the experts were able to generate new knowledge that was used to guide them in the right direction toward the fault. These experts then generated hypotheses that were logical and relevant to the previously obtained information which they tried to verify with powerful technical evaluations. This process continued until the problem fault was determined.

Contrasting this expert behavior with that of the novice it is clear that the novices did not have the amount of knowledge that the experts had. Also, because of lack of experience, the novices did not have their knowledge efficiently organized. This lack of organized knowledge prevented the novices from having the patterns that the experts seemed to rely so heavily on. The novices began with the same initial symptoms but were often unable to determine what the important symptoms were and when they were determined the novices could not come any closer to the fault. Hypotheses were generated but they were not necessarily based on previous information. Hypothesis selection did not seem to be closely aligned with any logical or efficient strategy and hypothesis verification was attempted with weak, unreliable, sensory dominated tests.

Knowledge base content. This study supports the theory that experts have more domain-specific knowledge than novices. The dependent measures used in this study provided evidence to suggest a large expert knowledge base. Other expert/novice comparison studies have also concluded that experts have more domain-specific knowledge than novices (Larkin, McDermott, Simon, & Simon, 1980; Magone & Yengo, 1976). It is this large knowledge base that helps explain the experts' ability to make better selections. They have more selections to choose from and they know how to interpret the results. The novices have less information in their knowledge base to access and therefore must rely on the limited options they have available to them.

Knowledge base structure. This study also supports the theory that experts have organized their knowledge into complex structures that link the abstract conceptualizations of the domain with the surface features of the system (Chi, Glaser, & Rees, 1982). The organization of the knowledge base relates closely with the development of mental models or schemas. It is likely true that all humans have some form of mental model or conceptualization of the operation and function of any piece of technical equipment. Whether accurate or not, this knowledge organization helps people recall information and make decisions by tracing through the structure (Anderson, Spiro, & Anderson, 1978). This appears to be exactly what the experts did on their troubleshooting tasks in this study. Using the various search techniques described by Rasmussen and Jensen (1974), the experts traced through the system in an ideal path from the initial problem symptom to the identification of the problem fault. Their efficient and logical solution paths were graphically portrayed on the problem behavior graphs of each subject. The experts had little difficulty keeping their search for information and generation of hypotheses within the actual problem space. Further support for the theory of a mental model to guide troubleshooting was generated by contrasting the expert performance with the seemingly random appearance of the novice problem behavior graphs.

Problem type. The influence of the type of problem provided an interesting interaction with expert performance. On the fuel pump problem, the novices were able to perform at a level nearly equal to the experts. They were able to select and obtain specific and relevant information and were able to generate logical and efficient hypotheses. One explanation for the expert-like behavior of the novices is that they, as a group, had more work experience in the mechanical domain than in the magnetic or electrical domains. Obviously the novices had developed a certain amount of expertise in the mechanical domain. When the fault changed from a problem with a mechanical emphasis to one with an electrical emphasis, the performance of the novices changed drastically. On the wire problem the novices had difficulty selecting and obtaining specific and relevant information. Without their knowledge and experience to rely on they were now forced to search for general information that was likely to be irrelevant and was often not even obtained. The novices on the wire problem also generated numerous hypotheses that were primarily irrelevant, illogical, and inefficient.

The major differences between the two problems was that the fuel pump problem was primarily mechanical in nature and involved fuel and ignition systems that are similar to those found on virtually any internal combustion engine. The procedural tests needed to solve the problem were very surface oriented and could involve the acquisition of sensory information. The wire problem was primarily electrical in nature and contained some parts that are found only on a particular generator. The procedural tests needed for this problem were the deeper, more abstract, technical evaluations.

These differences help define the limits of the novices' areas of expertise. They appear to have some expertise in the mechanical domain with a very limited amount in the electrical domain. The experts' have a much larger amount of expertise that encompasses all three of the domains of knowledge within the generator: mechanical, magnetic, and electrical. This finding presents an important characteristic of expertise. Expertise cannot be thought of as domain-specific until the domain is accurately defined. As the task analysis showed, the generator domain includes the interaction of three domains. The experts displayed knowledge and experience in all three domains while the novices displayed expertise in only the mechanical domain. Had this study presented its subjects with only the fuel pump problem, faulty conclusions may have been reached regarding differences between expert and novice troubleshooting behavior. Future research into the nature of domain-specific expertise will need to account for the possibility of sub-domains of expertise and examine the interaction between expertise and problem type.

Technical troubleshooting processes. The results of this study support the theory that the primary troubleshooting process is hypothesis generation and acquisition. The development of the Technical Troubleshooting Model through the synthesis of prior research studies (Bouwman, 1983; Elstein, Shulman, & Sprafka, 1978; Sweller & Levine, 1982) provided an accurate representation of the troubleshooting process. Both groups proceeded through the Model by acquiring and interpreting information and by generating and evaluating hypotheses. While the protocols provided an incomplete account of the troubleshooting process, they were complete enough to allow a reasonable inference to be made regarding the use of the Model. Hayes (1981) uses a metaphor of a porpoise breaking the surface of the water in the ocean to describe the process of protocol analysis. The observer is able to detail the porpoise's actions while it is above the water but must infer its actions when under the water surface. This is similar to the analysis of mental processes. The protocols provide a trace of what the subject was thinking but the observer's task is to infer the processes that occured during the incomplete portions of the protocol. The protocols collected in this study did not provide a continuous trace of the subjects' mental processes although, by using the Model as a guide, substantial evidence exists to support the validity of the Technical Troubleshooting Model.

Limitations

Care must be taken to carefully interpret the findings of this study. Three concerns must be addressed to place this study in perspective. First, while the sample size was small and the subjects were not selected randomly, the *t* - test results were significant well beyond the .01 level. Even if little stock is placed in the statistical significance of the findings, the test results do provide a good indicator of the differences between the two groups as well as provide a measure of validity for the selection procedures. Second, it is important to realize that this study was designed and conducted for the purpose of contrasting expert behavior with novice behavior. Its purpose was not to verify a theory nor to find causal reasons for the development of expertise. The primary purpose was to provide descriptive evidence to aid the development of the theory of expertise. Third, the results of this study cannot, and will not, be generalized to a population other than the limited population of generator troubleshooters from which the subjects were selected. The results can, however, be used as indicators for further investigations of troubleshooting in other technical systems.

Implications for Instruction

This study was conducted with support from the Training and Development Research Center and the Minnesota Research and Development Center at the University of Minnesota and through the Training Service School at Onan Corporation in Minnesota. These three organizations have a common interest in the improvement of training and education in either the public or private sectors of the ecomony. The implications of this research should therefore focus on the improvement of technical instruction.

From the results of this study it is obvious that there are clear differences between expert and novice technical troubleshooters. A major goal of technical instruction is to provide students with knowledge and skill and to guide them in the development of expertise. This study provides some answers to the question: What is expertise? This study has shown that expertise in technical areas includes the development of a substantial knowledge base that contains knowledge of basic principles and specific system information. This knowledge base is organized in a way that allows the expert to access the knowledge base to select further information and to develop potential solutions.

What does this mean for technical instruction? This study illuminates three areas that must be emphasized to improve technical instruction. First, for technical instruction to be effective, the content domain must be adequately and completely defined. Questions regarding the domain boundaries, the structure of the domain, and the content within the domain must be answered. This study provided one example of a complete analysis of a technical domain. The cognitive task analysis identified the three sub-domains within the larger domain of generators and the important content to be taught for each sub-domain. This information would likely be obtained by any experienced instructor although the level of detail provided by the cognitive task analysis approach goes well beyond the scope of normal instructional design. As described in this study, the use of the cognitive task analysis provided a broad description of the technical system through the development of the system map. This map was then used to further describe various problems through the development of the problem space maps. Through these mappings a much clearer picture of the system and the specific nature of several potential faults was gained. By expending the effort required by the cognitive task analysis approach, the instruction designer can gain a greater understanding of the system and will be able to use that new knowledge to develop more effective instruction.

Secondly, technical instruction must include domain-specific content. This content can include the theoretical information that underlies the domain but it should not be taught at the expense of specific system related information. Students must be taught the function and operation of the technical system under study. They must comprehend the relationships between the individual parts and the total system. Instructors must be aware of the need for students to develop an accurate mental model of the system and should explicitly teach an idealized system model. Instruction must also cover the technical evaluation procedures that are likely to be needed. Students must know what procedures are available, when they should be used, how they are done, and what the results mean.

The third area of emphasis for technical instruction is to provide students with realistic learning experiences. Students should be given systems that do not function properly and have them work through the troubleshooting process to identify the system fault. This experience should be formalized in a manner that requires the students to record initial symptoms, desired information, potential hypotheses, and useful technical evaluations. By recording these important factors in the troubleshooting process, instructors will be able to identify mistakes and omissions in the students' problem solving processes. These realistic learning experiences provide students with the opportunity to develop and strengthen their understanding of the system by integrating the formal knowledge with the practical experience (Kolodner, 1983). It is through practice that the organization of knowledge and the development of patterns occurs. Without practice it is doubtful that the transformation from novice to expert could take place.

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Appendix A
Subject Questionaires

ONAN SERVICE TRAINING

REGISTRATION CONFIRMATION WORKSHEET

Please complete this form and return it to Onan in the enclosed envelope at least two weeks prior to the beginning of training. This information will be used to help make your Onan training experience meet your specific needs. All information will remain confidential.

NAME: ______________________ (last) ______________________ (first)

EMPLOYER: ____

EMPLOYER'S ADDRESS: ______________________________

____

____

PART 1: WORK EXPERIENCE.

A. Which best describes your present position? (If you work in more than one area, see the note below.)

___ Service ___ Sales ___ Parts ___ Management ___ Other

NOTE: If your job includes more than one area, indicate by percent how much time you spend in each area. Example:

60% Service 20% Sales — Parts 20% Management — Other

B. How long have you been in your present position?

_________ Years _________ Months

C. Do you have any previous work experience with engine driven generators?*

_________ Years _________ Months _________ None

D. Do you have any previous work experience with engines and/or mechanics?*

_________ Years _________ Months _________ None

E. Do you have any previous work experience with electricity and/or electronics?*

_________ Years _________ Months _________ None

*Be sure to include any military work experience that applies.

PART 2: EDUCATION AND TRAINING

Please describe any formal instruction you have received in electrical and/or mechanical subjects. Include the type of program and its approximate length.

A. VOCATIONAL SCHOOLS:

(Examples: Nine-month Evening Small Engine Program; Two-year Diesel Program.)

____

____

____

____

B. MILITARY SCHOOLS:

(Examples: Four-month Power Generation Technician School; Six-month Electronic Technician School.)

____

____

____

____

C. COLLEGE COURSES:

(Examples: One course in Beginning Electronics; Two courses in Engine Systems.)

____

____

____

____

D. FACTORY TRAINING:

(Examples: Two-day Onan school at distributor; One week Briggs & Stratton Engine school.)

____

____

____

____

PART 3: YOUR GOALS AND EXPECTATIONS

A. Describe any special concerns or things you want to learn while attending an Onan factory training course.

____

____

____

____

____

____

THANK YOU!

Appendix B
Consent Form

RESEARCH CONSENT FORM

You are invited to participate in a study of technical troubleshooting performance. We hope to learn how people differ in the ways they attempt to solve technical problems. You were selected as a possible participant in this study because of your level of expertise with electric generator sets.

If you decide to participate, we will ask you to troubleshoot a faulty generator set. The generator set will have a specific problem and you will need to locate the fault. As you work through the problem we will ask you to "think aloud." This will involve saying whatever you are currently thinking as you work through the problem. We will be recording your verbalizations and will use them to analyze how you solved the problem. This task will take you about one hour.

In addition to solving the actual problem, we will ask you to take a test that covers information related to the function and operation of electric generator sets. You will also be asked to make several basic tests such as voltage readings and continuity tests.

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

Your decision whether or not to participate will not prejudice your relations and opportunities with the Onan Service Training School. If you decide to participate, you are free to discontinue participation at any time without prejudice.

If you have any questions, please ask. If you have any questions at a later date, you may contact me at (612) 624-1214.

Thank you,

Scott D. Johnson

You are making a decision whether or not to participate in this research study. Your signature indicates that you have read the information provided above and have decided to participate. You may withdraw at any time without prejudice after signing this form should you choose to discontinue participation in this study.

____

Signature Date

Signature of Investigator____________________

Appendix C
Knowledge Exams

Name____________________

MAGNETIC FUNDAMENTALS

Instructions: 1. Carefully read each question and select the one best answer.

2. Circle the letter of your answer. Example: Ⓐ

1. Which of the following occurs when a conductor moves across a magnetic field?
    a. Voltage is induced in the conductor.
    b. The magnetic field strength increases.
    c. The magnetic field strength decreases.
    d. Voltage is reduced in the conductor.

2. Reversing the current flow through a coil
    a. reduces the amount of flux produced.
    b. reverses its two-pole field.
    c. reduces the amount of power consumed.
    d. reduces eddy currents.

3. The ability of a magnetic substance to remain magnetized after the magnetizing force is removed is called
    a. persistance.
    b. permeability.
    c. hysteresis.
    d. retentivity.

4. The voltage output of an AC generator is usually controlled by
    a. varying the number of windings in the stator.
    b. varying the DC exciter voltage.
    c. varying the reluctance of the air gap.
    d. shorting out part of the armature windings.

5. The output frequency of an AC generator is dependent upon the
   a. number of poles and phases.
   b. rotor speed and phases.
   c. number of poles and the type of prime mover.
   d. number of poles and the rotor speed.

6. The shape of the lines of force around a current-carrying conductor is
   a. oval.
   b. horseshoe.
   c. circular.
   d. parabolic.

7. The current induced within the iron core on which the armature coils are wound is the
   a. primary current.
   b. negative current.
   c. eddy current.
   d. secondary current.

8. The application of heat to a magnet will
   a. weaken it.
   b. leave it unaffected.
   c. strengthen it.
   d. reverse its polarity.

9. A great number of magnetic lines of force considered together are spoken of as
   a. magnetic flux.
   b. declination.
   c. consequent lines of force.
   d. magnetic cores.

10. When the sides of the armature coil move at right angles to the magnetic flux
    a. highest voltage is produced.
    b. medium voltage is produced.
    c. low voltage is produced.
    d. zero voltage is produced.

11. Frequency of alternating current depends directly on the
    a. direct current input.
    b. strength of magnetic field.
    c. number of windings in the armature.
    d. rotating speed of the armature.

12. Induced voltage can be increased by
    a. increasing the magnetic field strength.
    b. increasing the speed of the lines of force cutting across a conductor.
    c. increasing the number of conductors cutting through the lines of force.
    d. all of the above.

13. Magnetism created by a flow of electric current is
    a. indicated magnetism.
    b. electromagnetism.
    c. mutual mangetism
    d. potential magnetism.

Name____________________

ELECTRICAL FUNDAMENTALS

Instructions: 1. Carefully read each question and select the one best answer.

2. Circle the letter of your answer. Example: Ⓐ

1. A fundamental law of electricity is that the current in a circuit is
    - a. inversely proportional to the voltage.
    - b. equal to the voltage.
    - c. directly proportional to the resistance.
    - d. directly proportional to the voltage.

2. Resistance is always measured in
    - a. coulombs.
    - b. henrys.
    - c. ohms.
    - d. mhos.

3. The unit of Electro Motive Force (EMF) is the
    - a. ampere.
    - b. volt.
    - c. ohm.
    - d. watt.

4. What type of electrical circuit contains all of it's components "in line"?
    - a. Series
    - b. Parallel
    - c. Series-parallel
    - d. Electro-mechanical

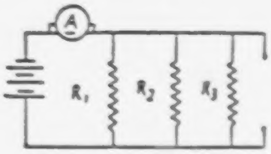
5. In the circuit below, if an additional resistor were placed parallel to R3, the ammeter reading would

   a. increase.

   b. decrease.

   c. remain the same.

   d. drop to zero.



6. In a parallel circuit containing a 4-ohm, 5-ohm, and 6-ohm resistor, the current flow is

   a. highest through the 4-ohm resistor.

   b. lowest through the 4-ohm resistor.

   c. highest through the 6-ohm resistor.

   d. the same for all (equal through all resistors).

7. The electrical pressure in a circuit is called

   a. power.

   b. voltage.

   c. resistance.

   d. capacity.

8. Induced voltage always lags the current it creates by

   a. 45 electrical degrees.

   b. 90 electrical degrees.

   c. 120 electrical degrees.

   d. 360 electrical degrees.

9. A circuit that has equal amounts of inductive and capacitive reactance is said to be

   a. conductive.

   b. resonant.

   c. anomalous.

   d. electrostatic.

10. The total opposition to current flow in a circuit containing resistance and reactance is called

    a. conductance.

    b. reluctance.

    c. impedance.

    d. inductance.

11. The process by which current in one conductor creates a voltage in another is

    a. induction.

    b. capacitance.

    c. conductance.

    d. lamination.

12. Amperage is

    a. the opposition to current flow through a conductor.

    b. the pressure pushing the current through a conductor.

    c. the rate at which current flows through a conductor.

    d. measured in terms of ohms.

13. Resistance is

    a. the opposition to current flow through a conductor.

    b. the pressure pushing the current through a conductor.

    c. the rate at which current flows through a conductor.

    d. measured in terms of voltage.

14. According to Ohm's Law

    a. to find the amperage, multiply the voltage by the resistance.

    b. to find the voltage, divide the amperage by the resistance.

    c. to find the resistance, multiply the voltage by the amperage.

    d. none of the above are correct.

Name_____________________

MECHANICAL FUNDAMENTALS

Instructions:
1. Carefully read each question and select the one best answer.
2. Circle the letter of your answer. Example: Ⓐ

1. The correct sequence of the four strokes in a four cycle engine is
   - a. intake, power, compression, exhaust.
   - b. intake, compression, power, exhaust.
   - c. intake, exhaust, compression, power.
   - d. intake, compression, exhaust, power.

2. Using a leak down tester, you observe 40% leakage and a whistling noise at the dipstick tube. What problem have you isolated?
   - a. Bad valve seating.
   - b. Bad rings.
   - c. Worn intake guides.
   - d. Crankcase vacuum problem.

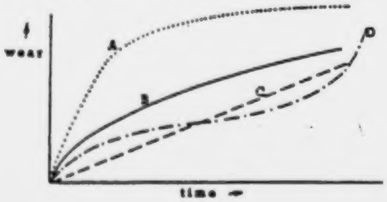
3. The bottom ring on an Onan engine helps control
   - a. engine noise,
   - b. compression loss.
   - c. valve guide wear.
   - d. oil consumption.

4. After a complete bore measurement, you find the bottom of the bore to be 3.256" and the top of the bore to be 3.252". What is a likely cause?
   - a. Missing air filter.
   - b. Normal wear.
   - c. Dirty oil.
   - d. All of the above.

5. Which component in Onan 2-cylinder engine governors is most responsible for increasing throttle position when a load is applied?
   a. The flyballs and governor cup.
   b. The governor spring.
   c. The sensitivity clip.
   d. The speed adjust nut.

6. A valve stem seal is found most often on
   a. intake valves.
   b. oil pressure relief valves.
   c. crankcase breather valves.
   d. exhaust valves.

7. On the graph below, which line best indicates how an engine wears over time?
   a. Line A.
   b. Line B.
   c. Line C.
   d. Line D.



8. An engine with approximately 100 hours use is using abnormal amounts of oil. It is not leaking oil. A partial teardown reveals that the cylinder bore is glazed. What is the most probable cause?
   a. Use of poor quality fuel.
   b. Incorrect weight of oil.
   c. Excessive loading during break-in.
   d. Insufficient load during break-in.

9. What state must the air/fuel mixture be in for good combustion?
   a. Liquid.
   b. Vaporized.
   c. Solid.
   d. None of the above.

10. If there were no friction,
    a. input would be less than output.
    b. output would be less than input.
    c. output would equal input.
    d. there could be no work.

11. Pistons are cam-ground to allow for
    a. extra valve lift.
    b. lower compression.
    c. expansion with increased temperature.
    d. none of the above.

12. In an engine, energy loss is usually in the form of
    a. mechanical energy.
    b. friction and heat.
    c. chemical energy.
    d. radiant energy.

13. Which of the following is a poisonous gas given off from a running gasoline engine?
    a. Carbon dioxide.
    b. Carbon monoxide.
    c. Nitrogen.
    d. Oxygen.

14. Conduction is the movement of heat
    a. by electromagnetic waves.
    b. by using water or air as a carrier.
    c. through a substance.
    d. all of the above.

NAME____________________________
# CORRECT_______________________
% CORRECT_______________________

Calculation Exam
Part 1

Instructions: Answer the following calculation questions to the best of your ability. Please show the formula you used and your calculations on this paper. Please circle your answer.

1. What is the output of a GenSet which has a load of 54 amps at 120 volts, with unity power factor?

   Formula:

   Answer:

2. Lamps having a resistance of 10 ohms, 40 ohms, and 60 ohms respectively are connected in series. What is the total resistance of the circuit?

   Formula:

   Answer:

3. A resistor of 5 ohms is connected in parallel with a resistor of 20 ohms. What is the equivalent resistance of these resistors?

   Formula:

   Answer:

4. Four lamps, each drawing 1/2 ampere, are connected in parallel across a 110-volt generator. What is the current flowing in the entire circuit?

   Formula:

   Answer:

5. How many watts will a fully loaded 5 kVA alternator produce at 80% power factor?

   Formula:

   Answer:

6. What frequency does a two-pole generator produce when operating at 3000 RPM?

   Formula:

   Answer:

7. The current coil of a certain ammeter has a resistance of .02 ohms. What is the voltage drop across this coil when it is carrying 20 amperes?

   Formula:

   Answer:

8. How much current is needed to operate a soldering iron which has a rating of 600 watts at 100 volts?

   Formula:

   Answer:

9. What is the current in a series circuit with a 3-ohm resistor connected to a 24-volt battery?

   Formula:

   Answer:

10. What is the resistance in a circuit with 2 amperes of current and 12 volts?

    Formula:

    Answer:

NAME_________________________
# CORRECT____________________
% CORRECT____________________

Calculation Exam
Part 2

Instructions: Using the given formulas, answer any of the following calculation questions that you answered incorectly on the previous exam. Please show your calculations on this paper and circle your answer.

1. What is the output of a GenSet which has a load of 54 amps at 120 volts, with unity power factor?

   Formula: $kW = \frac{I \times E \times PF}{1000}$

   Answer:

2. Lamps having a resistance of 10 ohms, 40 ohms, and 60 ohms respectively are connected in series. What is the total resistance of the circuit?

   Formula: $R_T = R_1 + R_2 + R_3$

   Answer:

3. A resistor of 5 ohms is connected in parallel with a resistor of 20 ohms. What is the equivalent resistance of these resistors?

   Formula: $R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$

   Answer:

4. Four lamps, each drawing 1/2 ampere, are connected in parallel across a 110-volt generator. What is the current flowing in the entire circuit?

   Formula: $E = I \times R$

   Answer:

5. How many watts will a fully loaded 5 kVA alternator produce at 80% power factor?

   Formula: $PF = \frac{kW}{kVA}$

   Answer:

6. What frequency does a two-pole generator produce when operating at 3000 RPM?

   Formula: $F_{Hz} = \frac{N \times RPM}{120}$

   Answer:

7. The current coil of a certain ammeter has a resistance of .02 ohms. What is the voltage drop across this coil when it is carrying 20 amperes?

   Formula: $E = I \times R$

   Answer:

8. How much current is needed to operate a soldering iron which has a rating of 600 watts at 100 volts?

   Formula: $W = E \times I$

   Answer:

9. What is the current in a series circuit with a 3-ohm resistor connected to a 24-volt battery?

   Formula: $E = I \times R$

   Answer:

10. What is the resistance in a circuit with 2 amperes of current and 12 volts?

    Formula: $E = I \times R$

    Answer:

ONAN SERVICE TRAINING

Progress Test
EMERALD CONTROL

Name:_______________
# Correct_____
% Correct_____

INSTRUCTIONS:

1. *Carefully read each question and select the one best answer.*
2. *Blacken the letter of your answer, Example (A).*
3. *Use Onan Print # 611-1174 for this test.*

1. What do components K3, K4, R1, K2 have in common?

A. All are part of the start system.

B. All are part of the stop system.

C. All are mounted on the A1 board.

D. All are D.C. components.

2. Component A1-CR1's function is:

A. Rectify AC to DC for battery charging.

B. To prevent battery discharge when not running.

C. Rectify AC to DC to power B1.

D. Both A & B.

3. Component A1-K2 and A1-K3 could be described as:

A. Run relays

B. Crank relays

C. Stop relays

D. Start relays

4. Component S2's function is:

A. To Close on oil pressure

B. To Open on oil pressure

C. To lock-out start ignition until oil pressure rises

D. A & C

5. *How many volts would you expect to find at A1-P3-6 unit running?*

   A. *0 volts*

   B. *6 - 7 volts*

   C. *13 - 14 volts*

   D. *120 volts*

6. *How many volts would you expect to find at A1-P3-6 unit cranking?*

   A. *0 volts*

   B. *4 - 6 volts*

   C. *10 - 12 volts*

   D. *120 volts*

7. *When the stop switch is depressed the unit continues to run. Which of the following is a possible cause?*

   A. *A1 - CR2 Open*

   B. *A1 - CR2 Shorted*

   C. *A1 - CR3 Open*

   D. *A1 - CR3 Shorted*

8. *Which stator winding provides battery charging, choke pull off, and run signal to the control?*

   A. *T1 - T2*

   B. *T3 - T4*

   C. *S1 - S2*

   D. *B1 - B2*

9. *Relay K5 is:*

   A. *The stop relay*

   B. *Used only on gaseous fueled sets*

   C. *Part of the remote control*

   D. *An A.C. powered component*

10. With fuse A1 - F1 removed the set will:

    A. Start but not run

    B. Crank but not start

    C. Run but not stop

    D. Do absolutely nothing

11. When the set is being cranked, but has not yet started B+ to the ignition coil is supplied thru:

    A. Closed set of A1 - K4 contacts

    B. Closed set of A1 - K3 contacts

    C. Closed set of K5 contacts

    D. Closed set of K1 contacts

12. The set starts but kills when the start switch is released. What *IS NOT* a possible cause:

    A. No A.C. output from B1 - B2 winding

    B. Defective K2 relay

    C. Open A1 - CR3

    D. Defective K3 relay

13. To obtain maximum no-load A.C. output voltage connect leads S1 and CR4 - AC to connections

    A. X1, X6

    B. X3, X6

    C. X1, X4

    D. X3, X4

14. Which of the following *IS NOT* a D.C. powered component?

    A. A1 - K3

    B. B1

    C. H1

    D. B3

15. The unit starts at the set but not at the remote. What is a possible cause?

    A. Defective K1

    B. Defective S1

    C. Open at A1-P3-3

    D. Open at A1-P3-6

16. When the start switch is pressed the set fails to crank. A voltage check indicates 12 volts at terminal S1 on relay K1 with the start switch pressed. What component would your check next?

    A. S2

    B. K2

    C. K4

    D. B1

17. S3, the ignition points, open & close to cause T1, the ignition coil, to fire E1 & E2, the spark plugs, in which sequence

    A. S3 closes, E1 & E2 fire, S3 opens

    B. S3 opens, E1 & E2 fire, S3 closes

    C. S3 opens, E1 fires, S3 closes, S3 opens, E2 fires, S3 closes

    D. S3 closes, E1 fires, S3 opens, S3 closes, E2 fires, S3 opens

18. R6's function is primarily:

    A. Battery charging

    B. Unit cranking

    C. Unit stopping

    D. Ignition suppression

19. *Unit not running, a jumper is connected between A1-P3-3 and A1-P3-1. The unit will now:*

    A. Do nothing

    B. Have a blown F1 fuse

    C. Start on fire

    D. Start

20. *No indication from a battery condition meter (BCM) in an A3 Standard Remote Control could be caused by:*

    A. Loose A1-P3-6 connection

    B. Defective K1

    C. Open A1-CR2

    D. None of the above

Disk 23
Emerald
6/18/86

Name____________________

Procedural Knowledge
-- Sources of Information --

Instructions: Using the Onan Service Manual for the BGE-BGEL GenSets, find the following information and list the page where it is located.

______ On what page can you find the causes of low oil pressure in the engine?

______ On what page can you find the procedures for testing the CR4 bridge rectifier?

______ On what page can you find the causes for the engine cranking but not starting?

______ On what page can you find the causes of the generator overheating?

______ On what page can you find a schematic drawing of a typical BGE control unit?

______ On what page can you find the specifications for the BGE GenSet?

Instructions: Using the Parts Manual for the BGE-BGEL GenSet, find the part number for each of the following items.

______ BGE Control Wiring Harness (with 8-pin connector)

______ Battery Condition Meter for Remote Start Control

______ Transformer-Regulator

______ Starter Repair Kit

______ Ignition Coil

______ Ignition Tune-up Kit

______ Air Cleaner Element for Gasoline Fuel System

______ Piston Ring Set (.020" oversize)

______ Breather Reed Valve

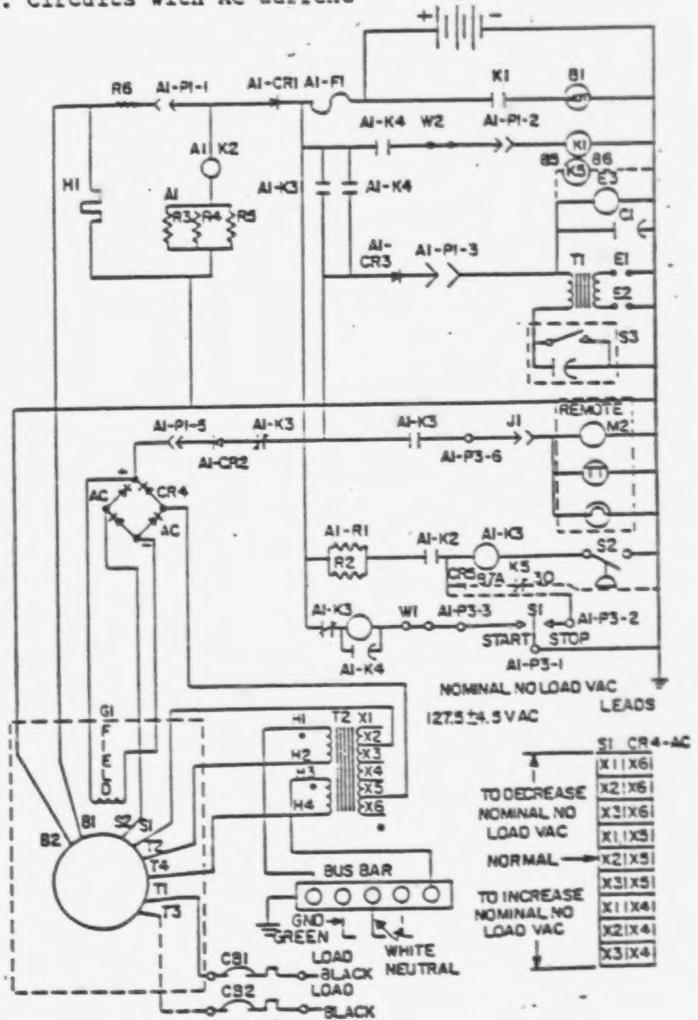
______ Camshaft Bearing

Name____________________

Declarative Knowledge
-- Reading Schematic Drawings --

Instructions: 1. Using the schematic drawing for the BGE GenSet, determine which circuits are energized while the GenSet is RUNNING.
2. Trace the energized circuits using the following colors:

Red . . . Circuits with B+ current
Green . . Circuits with B- ground
Blue. . . Circuits with AC current


BT1
+
−
R6
A1-P1-1
A1-CR1
A1-F1
K1
B1
A1-K4
W2
A1-P1-2
K1
85
86
K5
E3
A1 K2
H1
A1
R3
R4
R5
A1-K3
A1-K4
C1
A1-CR3
A1-P1-3
T1
E1
S2
S3
REMOTE
A1-P1-5
A1-K3
A1-CR2
A1-K3
A1-P3-6
J1
M2
T1
AC
CR4
AC
A1-R1
R2
A1-K2
A1-K3
S2
CR5
87A
K5
30
A1-K3
W1
A1-P3-3
S1
A1-P3-2
START
STOP
A1-K4
A1-P3-1
NOMINAL NO LOAD VAC
127.5±4.5 VAC
LEADS
G1
F
I
E
L
D
H1
T2
X1
X2
X3
X4
X5
X6
H2
H3
H4
B2
B1
S2
S1
T2
T4
T1
T3
BUS BAR
GND
GREEN
WHITE
NEUTRAL
CB1
LOAD
BLACK
CB2
LOAD
BLACK
S1
CR4-AC
X1 X6
X2 X6
X3 X6
X1 X5
X2 X5
X3 X5
X1 X4
X2 X4
X3 X4
TO DECREASE NOMINAL NO LOAD VAC
NORMAL
TO INCREASE NOMINAL NO LOAD VAC

W1,2					JUMPER-WIRE
T2					TRANSFORMER
T1					IGN COIL
S3					IGN POINTS
S2					SWITCH- LOW OIL PRESSURE
S1					SWITCH-START/STOP
R6					RESISTOR-BATTERY CHARGE
K5					RELAY-USED WITH LPG ONLY
K1					START SOLENOID
H1					CHOKE
G1					GENERATOR
F1					FUSE
E3					FUEL PUMP/OR FUEL SOLENOID
E1,2					SPARK PLUG
CB1,2					CIRCUIT BREAKER (AC OUTPUT)
CR4					BRIDGE RECTIFIER
CR5					RECTIFIER-USED WITH LPG ONLY
C1					CAPACITOR
BT1					BATTERY 12V
B1					STARTER
A3					STANDARD REMOTE CONTROL
A2					DELUXE REMOTE CONTROL
A1	300-2878		C	REF	CONTROL ASSY
Item	Part No.	[illegible]	[illegible]	Qty	[illegible]

Appendix D

Content Validity Rating Sheets

College of Education

UNIVERSITY OF MINNESOTA
TWIN CITIES

Department of Vocational and Technical Education
Office of Special Services
Vocational and Technical Education Building
1954 Buford Avenue, Room 210
St. Paul, Minnesota 55108

(612) 624-1700

January 1, 1987

Technical Trainer
Onan Corporation
1400 73rd. Avenure N.E.
Minneapolis, MN 55432

Dear

The following three exams relate to the basic principles that underlie the operation of generator sets. These basic principles have been divided into three knowledge areas; electrical, magnetic, and mechanical. The exam items have been selected as representative samples from the domains of electrical, magnetic, and mechanical knowledge as defined on the following pages. Each exam has been designed to provide a complete coverage of the domain with a larger proportion of questions being devoted to the major concepts within the domain.

You, as a subject matter expert in the field, are being asked to validate each of the items on each exam. Please review each item and rate its relevance to the domain by placing a circle around the appropriate number. Items are relevant if they relate to information that is definitely in that domain. Items are not relevant if they relate to information that does not belong in the domain.

In addition to rating each item, please look for any important omissions in the domain coverage of each exam. If you feel any important concepts or principles have been neglected, please indicate those in the comment section.

Thank you for your assistance,

Scott D. Johnson
Research Assistant
University of Minnesota

ELECTRICAL DOMAIN

Domain Definition: The electrical domain has been divided into three primary content areas: basic electrical principles, electrical measurement, and electrical circuits.

Basic Electrical Principles: includes electron theory, theory of electron flow, and the nature of conductors and insulators.

Electrical Measurement: includes the terms and definitions used when measuring electricity.

Electrical Circuits: includes the types of electrical circuits and characteristics of each type.

Item #	Very Relevant	Not Relevant	Relevant
1	3	2	1
2	3	2	1
3	3	2	1
4	3	2	1
5	3	2	1
6	3	2	1
7	3	2	1
8	3	2	1
9	3	2	1
10	3	2	1
11	3	2	1
12	3	2	1
13	3	2	1
14	3	2	1
15	3	2	1
16	3	2	1
17	3	2	1
18	3	2	1
19	3	2	1
20	3	2	1
21	3	2	1
22	3	2	1
23	3	2	1
24	3	2	1
25	3	2	1
26	3	2	1
27	3	2	1
28	3	2	1

Comments:

MAGNETIC DOMAIN

Domain Definition: The magnetic domain has been divided into two primary content areas: basic magnetic principles and those magnetic principles that are used in generators.

Basic Magnetic Principles: includes characteristics of magnetism (i.e. polarity, fields, lines of force), the effect of magnetism on current flow, and common magnetic terms and definitions.

Magnetic Principles used in Generators: includes the application of the basic magnetic principles used in the function and operation of generators.

Item #	Very Relevant	Relevant	Not Relevant
1	3	2	1
2	3	2	1
3	3	2	1
4	3	2	1
5	3	2	1
6	3	2	1
7	3	2	1
8	3	2	1
9	3	2	1
10	3	2	1
11	3	2	1
12	3	2	1
13	3	2	1
14	3	2	1
15	3	2	1
16	3	2	1
17	3	2	1
18	3	2	1
19	3	2	1
20	3	2	1
21	3	2	1
22	3	2	1
23	3	2	1
24	3	2	1
25	3	2	1
26	3	2	1
27	3	2	1
28	3	2	1
29	3	2	1
30	3	2	1
31	3	2	1

Comments:

MECHANICAL DOMAIN

Domain Definition: The mechanical domain includes the basic mechanical principles that underlie the operation of the various subsystems within an internal combustion engine. These principles consist primarily of fundamental physics concepts.

Item #	Very Relevant	Relevant	Not Relevant
1	3	2	1
2	3	2	1
3	3	2	1
4	3	2	1
5	3	2	1
6	3	2	1
7	3	2	1
8	3	2	1
9	3	2	1
10	3	2	1
11	3	2	1
12	3	2	1
13	3	2	1
14	3	2	1
15	3	2	1
16	3	2	1

Comments:

Procedural Skills

In addition to the knowledge that troubleshooters must have to be effective, they must also have achieved a certain level of expertise in the performance of various basic procedures. This study will be investigating the ability of technical troubleshooters to perform these basic procedures. In order for this study to investigate valid procedures, I would like you, as a subject matter expert in the area, to list what you feel are the important skills that are needed to be an effective technical troubleshooter.

Procedural Skill #1: Troubleshooters need to use mathematical formulas accurately.

Please list the mathematical formulas you feel are important for a technical troubleshooter to know.

Procedural Skill #2: Troubleshooters need to be able to locate technical information from various sources.

Please list the sources in which a technical troubleshooter should be able to locate technical information.

Procedural Skill #3: Troubleshooters need to be able to perform various test procedures using various types of test equipment.

Please list the types of test procedures that a technical troubleshooter should be able to make.

Appendix E
Potential Problems

POTENTIAL BGE GENSET CONTROL SYSTEM PROBLEMS

	Occurance of Problem		Diagnosis of Problem	
	Frequent	Infrequent	Easy	Hard
Grounded condenser	✓			✓
Discharged battery		✓	✓	
Poor battery connections		✓		✓
Burned-out fuse		✓	✓	
Start solenoid not grounded		✓		✓
Defective start solenoid		✓	✓	
Defective starter		✓	✓	
Faulty start switch		✓		✓
Open between start switch and PC board		✓		✓
Open between start solenoid and PC board		✓		✓
Open between coil and PC board		✓	✓	
Defective PC board	✓		✓	
Worn or fouled spark plugs		✓	✓	
Worn ignition points		✓		✓
Incorrect timing		✓		✓
Faulty plug wires		✓	✓	
Sticking choke		✓	✓	
Faulty fuel pump		✓		✓
Incorrectly set carburetor mixture screws	✓			✓
Low oil level		✓	✓	
Defective LOP switch		✓	✓	
Low oil pressure		✓	✓	
Defective charge resistor		✓		✓
Open between generator and control		✓		✓
Sticking choke linkage		✓		✓
Incorrect choke adjustment	✓			✓
Open between choke heater and generator		✓		✓
Defective choke heater		✓		✓
Breaker points sticking		✓	✓	
Contaminated fuel		✓		✓
Defective charge windings		✓	✓	
CRI power rectifier open		✓	✓	

Appendix F

Protocol Instructions

PROTOCOL DIRECTIONS

You will be given two 4.0 kW GenSets that do not work properly. Your task will be to find the problem as quickly as possible. You do not have to repair the problem, only find the problem. Manuals, diagrams, and test equipment will be available to you. When you are sure you have found the problem, please say so. If it is not the problem, I will tell you so and then you can continue.

I am interested in what you are thinking as you try to find the problem. Therefore, I am going to ask you to "think aloud" as you work on the GenSet. I would like you to talk constantly by saying whatever you are thinking at the moment. Do not talk to me or tell me what you think you are thinking. Pretend you are alone as you work on this problem. If you are silent for a certain length of time, I will remind you to keep talking.

As you are talking, be sure to say what you think the problem is, what information you are looking for, where you are looking, what test mesurements you are making, and what the results of the tests are.

Before you begin, I would like you to practice "thinking aloud" with several practice exercises. First, I want you to multiply two numbers in your head and think aloud as you find the answer. What is the result of multiplying 12 X 24? (288). How many windows are there in your home?

You may begin troubleshooting now.

Appendix G
Subject Protocols

EXP 1-- FUEL PUMP PROBLEM
START 11:22 -- UNIT C

(Tries it)

(Starts but quits)

One more time here.

(Tries it again)

Ok, the symptom on this one is, you start it up, it fires, as soon as it fires, it shuts right down, so, try it one more just to verify everything, I got all the symptoms right first of all.

(Tries it again)

I'm getting one symptom here where it seems to start up and then it shuts down almost right away.

When I first started the thing, it seemed to run a slightly bit longer,

now when I try to start it it doesn't seem to run real good.

It runs a shorter time.

It's almost like it's out of gas.

I'm going to try it once more to verify that it's not the problem.

(Tries it again)

Ok, right now I have no gas,

and it doesn't seem to be firing.

I don't know if it's gas and I don't know if it's spark.

So my next move will be to disconnect one spark plug wire, inserting a screwdriver

and coming near a metal chassis to see if I still have spark.

(Check for Spark)

So now I'm going to crank it holding it,

the screwdriver a little ways from ground to see if I can get a spark to jump.

I've got a nice spark,

indicating I got spark to my spark plugs, I'm getting into, I could have a bad plug at this time, but it fired partially at one time, so I can assume that if it fired, the plugs would be good yet. If it had been that way, you'd have a problem with no firing at all, it did fire, so I can assume at this time that probably the plugs are ok yet, because it would be running rough if you had a bad spark plug or something. It might fire in one cylinder but I'm getting no firing.

So my first check would be, of course, depending on if it was in a coach or not, to check the fuel,

ah, we seem to have gas over here.

(Check Gas Tank)

Ah, my next deal is,

I can do one of two things,

I can either check to see if I have fuel through the pump,

I can also disconnect to the lead over here, seeing if I have B+ applied to electric fuel pump first of all. So, I'm going to take, get my meter set up,

and see if I have any voltage at my fuel pump first.

It's a little tough to get it off right now.

(Test Measurement -- Voltage - Fuel Pump)

Again setting my meter at the 50 volt range, making sure I'm going to be covered,

I have reinstalled my spark plug lead.

(Tries it)

I got voltage here,

so I know I have voltage at my fuel pump right now.

Next, I'm going to just go from the lead.

Just because you have voltage to here does not necessarily mean you have a good

coil in the fuel pump where it can pump.

Now I've got the lead unplugged so I'm not going to disconnect the battery cable at this time, because I have B+ disconnected from my fuel pump so I don't have to worry about

taking and damaging my meter by having B+ when I'm in the resistance scale.

I set the resistance up and I go to ground here.
(Test Measurement -- Resistance - Fuel Pump Coil)

I seem to have

oh

7 1/2 ohms,

so that would indicate the coil in my pump is probably good.

(Crack Fuel Line)

Next, I know that,

pretty well bet that I got it,

so what I'm going to do next is disconnect the fuel line, see if I have gas, I'm going to take and keep it away from the spark plug where there's a chance where

you might have bad insulation or something, there might be a little residual fuel in the line and it might spark,

arcing and causing a fire, so I'm going to stay away,

back from here more, and then put a rag on there to uh

catch the excess fuel so I don't have it leaking all over the place.

(Pause)

Ok,

I got a rag in here, I'm going to just very carefully crank this over now

(Tries it)

I verified that I had gas in my fuel tank, I've disconnected the fuel line

on the outlet end. I've held a rag over there to catch any excess gasoline.

I cannot get any fuel through there.

So it could be a plugged screen, no fuel supply to the system.

Next would be to the inlet side and see if you have fuel there.

Could be also a plugged uh fitting.

Lifting this fuel supply tank, I realize there's got to be gasoline in there because of the fact of the weight.

Although it doesn't tell me yet if it's plugged. So I'm going to try and tilt this so I can see if I have gasoline.

Ok, I've tilted it.

I have gas coming over here.

So I can assume that I have gas from the tank up to the fuel pump.

There's two possibilities, either your inlet or your outlet fitting could be plugged yet.

So next I'll remove the inlet fitting to the fuel pump,

because I have determined at this time that I cannot get any fuel out of the fuel pump.

So right now I'm removing the inlet fitting, because I have determined that there is fuel through there.

I look up to the light, and although light's kind of poor in here,

if I had a light or something

Flashlight would have to verify if I got in here.

I look at it from both sides, get a good view, inlet fitting is good.

So I reinstall the fitting

Although I've looked in the pump too at this time and made sure there was nothing right behind the fitting that was blocking it either.

This electric fuel pump does have a fuel filter, which can be checked too.

Now if I had a small wire or something, normally you'd just run on the

outlet side to make sure that hasn't plugged up with something.

It's quicker than take the fitting off, and the sealer and all this other stuff, it seems like it's open too.

Now either the fuel pump is bad or the filter assembly underneath.

Investigator -- Let's quit here.

STOP -- 11:31 TOTAL TIME TO SOLUTION = 9 MINUTES

EXP 2 -- FUEL PUMP PROBLEM
START 10:44

Ok, I guess because I don't know what the problem is on this set, the first thing I would probably try and do is give a visual inspection of the set to see if there were any obvious things wrong with the set that visually you could see.

Um,

probably

check the oil,

make sure that there's oil in the set

There seems to be plenty of oil

Air pre heater is in the summer position

Ok, I guess I'll just start the set then,

or attempt to start the set
(Tries to start)

The set cranks but doesn't fire.

I assume we have B+ going into everything except possibly the ignition or the fuel pump.

Another possibility is it might be out of gas.

Gasoline,

if the gauge is correct, there's a half a tank. So I assume that there is gasoline going up to the pump.

Next thing I'll do is check the voltage at the coil.

(Test Measurement -- Voltage - Coil)

Ok, I'll try and restart the set.

(Tries it)

Ok, there is voltage to the coil.

If there's voltage to the coil, there should be voltage to the pump.

Check the voltage to the pump.

Make sure the wire isn't pinched or something.

(Tries it)

Have high voltage going to the pump.

So I assume there is a correct, incorrect wire hooked up to the pump.

Um I'll have to pull off the front cover.

(Disconnect Battery)

(Removes Cover Panel)

Investigator -- Keep talking

(Schematic)

Ok, the wire,

I'm trying to find out where the wire that's connected up to the fuel pump goes.

It does say E2 and it does say it's going up to the ignition.

So

Check for continuity up to the ignition.

(Test Measurement -- Continuity to E3 (Coil))

From the fuel pump connection up to the ignition, up to the plus point on the ignition.

OK we do have continuity.

Now I don't understand why the voltage is so high.

Um

I'm going to redo that test and make sure that I'm reading what I think I'm reading.

Check for voltage again at the fuel pump.

(Test Measurement -- Voltage - Fuel Pump)

Trying starting (tries it)

I'm reading like 60 volts at the fuel pump.

Now

Um

The

wire that is marked E2 is going to the coil at the plus point

and I was getting 12 volts

up at the coil

I'll check the 12 volts again, to make sure that that's all I was getting up there.

Ah We now have

We now have extremely high voltage up there.

Is it same with the pump connected?

(Tries it)

No.

Pump is shunting some of the voltage.

Ok, the next thing I'll probably try is to trace back the wire

that is supposed to be going to

P1-3.

Disconnecting the circuit board

(Pause)

And I will probe from P1-3 on the connector up to the coil

(Test Measurement -- Continuity - Coil)

Ok, we do have continuity.

Ok, um,

I guess I am going to have to go back to schematic and look at the schematic.

(Pause)

(Schematic)

Investigator -- What are you looking for?

I'm just trying to see where the high voltage could be coming from.
Um,

P1-3 is connected up

to the board and goes through

the K4 contact, the K3 contact, and through the diode.

Um High voltage could

I assume only be coming from a couple of places,

and how it would get up there I don't know.

Investigator -- Keep talking Ron

(Visual Inspection)

I'm visually inspecting the inside of the control to see if there's anything obvious on the inside of the control, um

Grounds

up here to be connected where they're supposed to.

Um, question for you: Is it permissible to just replace the board?

Investigator -- Can you test the board? Why do you think it's the board?

Right this minute I don't know that it is the board.

Um, putting a new board in there takes the board out of it.

Investigator -- Ok, so you replace the board and you still have the same problem.

Ah Ha!

Um

I guess I don't really have any real answers or guesses even right at this point as to what it might be.

I guess I don't know.

Investigator -- Let's assume that high voltage has nothing to do with it.

It doesn't?

Ok. Um, if an engine gen set does not start, if it cranks but does not start, I assume one of two things. It's either no ignition

or um it's the fuel pump.

There is no fuel. I've checked B+ on the fuel pump and ignition and if there is no

if there is not a high voltage problem there, I assume that both the ignition and the fuel pump are operating correctly.

Um.

Points possibly, this is not my end of the business I just took the cover off, visual inspection of the points.

Um, visually inspecting they appear to be alright.

I'm lost, I'll admit it.

Investigator -- Ok, you're making some assumptions that things are Ok, and you don't really have any reason for assuming that.

If the problem is involved with the engine end, I'm not going to find it. (Laughs)

Investigator -- Ok, you've got it narrowed down, either ignition or fuel.

Yes

Investigator -- Ok. You can check ignition?

I suppose I could pull the spark plug out and see if the spark plugs are firing.

Investigator -- Ok, you might want to do that?

(Remove Plug)

I'm right now I'm pulling the spark plug out.

Looks carboned, it's very black

(Pause)

Plug the control board back in

Ok, and crank the set.

(Check Spark)

We have plenty of spark,

however the spark plug is dry.

Go around the other side and check the other spark plug.

The other spark plug is also dry.

Which probably means that it's not getting any fuel.

(Pause)

(Jump Fuel Pump)

Ok, I'm going to jump the fuel pump,

the B+ on the fuel pump right down to the battery

(Clicks)

It sounds to me like the fuel pump is not working.

Um

Do we have a fuel pump to change?

Investigator -- Ok, is there a way to test that?

Well, crack the fitting, see if any fuel comes out.

Investigator -- Ok, let's quit.

STOP -- 11:04 TOTAL TIME TO SOLUTION = 20 MINUTES

EXP 3 -- FUEL PUMP PROBLEM
START 11:22

(Cranking)

Won't even start huh.

(Cranking)

Look for the subtle things like did you put any oil in?

(Checks Oil)

There's a little bit in there. Not a whole lot.

But she doesn't start.

So

the first thing we'll do is see if we've got some coil voltage how's that?

(Test Measurement -- Voltage - Coil)

(Cranking)

I got about 9, 10 volts.

Investigator -- What should it be?

Oh well it depends what the battery voltage is I guess.

If that's battery voltage with it cranking.

(Cranking)

It's 11 down here.

Let's try it again.

(Cranking)

It's 9 volts but that should be enough to start it don't you think?

So we'll look at the other end of it and see what the points look like.

(Removes Points Cover)

(Cranking)

Well they moved.

But I don't see any fire there.
(Cranking)

I'm going to pull the plug to see if I've got anything.
(Removes Plug)

Eeee. Gadzooks.

Investigator -- What does gadzooks mean?

Lots of carbon on those plugs.

Ugh.

So I don't get bit

let me find a place to ground this.
(Cranking)

Plug fires.

It looked awful dry.

(Cranking)

But I don't hear the fuel pump running.

So let's see if we get anything to that.

Investigator -- What are you checking for?

Loose connections mostly.

(Test Measurement -- Voltage - Fuel Pump)

I'm going to measure voltage out of this ah fuel pump wire.

(Cranking)

I think my meter's screwed up here.
(Cranking)

I don't trust this meter.

I don't like these.

(Cranking)
60 volts.

(Cranking)

Which taint necessarily natural.

But the pump doesn't run.

(Cranking)

Doesn't run a lick. I don't see any fuel.
To confirm that we'll crack the line and see.

But I think that's why it won't start.

(Crack Fuel Line)

Don't want to come out huh?

Looks awful dry don't it.

(Cranking)

Nope, no fuel.

So we know why it won't start.

Know what came off of there.

(Schematic)

Well

the fuel pump

is getting 60 volts which would seem to be a little abnormal and it runs off of A1-P1-3.

Investigator -- Keep talking.

I don't have anything to say.

I'm thinking for a source of that voltage.

It seems like maybe it comes out of the bridge or something.
I gotta open up the box anyway.

(Open Cover)

Investigator -- What are you looking for?

(Looks At Board)

Oh anything burned or broken.

Something obvious.

I don't see anything.

But it's tough to work on these boards the way they're mounted so I may want to take it loose.

Fuel pump.

A1-P1-3.

I'm going to take the board loose.

Let me do one other thing.

Before I do that I'm going to test the pump.

See if it's any good.

Ouch.

(Jump Start Pump E-3 - Long Test)

(Whirring sound)

Doesn't seem to pull any fuel.

(Whirring sound)

or slow down.

Well let's crack the line again.

See if it's moving anything.

Pump ought to slow down once it gets the carburetor full.

(Whirring sound)

Bad fuel pump?

STOP -- 11:35 TOTAL TIME TO SOLUTION = 13 MINUTES

EXP 4 -- FUEL PUMP PROBLEM
START 10:35

Try starting it first.

(Cranking)

Ok first thing I want to do is check to see if I have ignition.

(Cranking)

(Test Measurement -- Voltage - Ignition Coil)

I do have voltage to the coil.

Well let's see.

I'll check and make sure the fuel pump is operating.

(Cranking)

(Test Measurement -- Voltage - Fuel Pump)

Fuel pump has voltage to it.

Seems quite a bit higher than what I would expect to see though.

Ah I'm going to check to see if it has

actually has spark.

(Removes Plug)

I'm going to take the spark plug out.

Put it back into the spark plug cable.

Ground the spark plug

and then crank the engine.

(Cranking)

I do have spark.

Next I'm going to loosen the bottom of the carburetor bowl to see if I have fuel.

(Disassembles Carburetor Bowl)

Maybe I won't.

Uh ha.

There's no fuel in the bowl.

I'm going to take the bowl off and check to make sure that the

float is not stuck.

Investigator -- Keep talking.

I'm now checking to see if the if the needle is actually moving along with the float and it appears to be moving with the float

so I'm going to put the carburetor

back together again.

(Reassembles Carburetor Bowl)

OK now

I'm going to try energizing the fuel pump

separately.

First I'm going to check the level in the gas tank.

OK.

Thought maybe you guys were getting tricky.

And all I'm doing is I'm going to connect a battery voltage directly to the pump.

(Jump Fuel Pump)

(Whirring)

Pump appears to operate.

Well.

Based on that

I'll say that the voltage that I was reading

should've been high enough to operate the fuel pump.

(Read Schematic)

E3 fuel pump. Looking at the print to see what powers the fuel pump.

And that's powered from the same point as the coil.

I'm going to take an ohmeter reading from the coil

to

the fuel pump.

(Test Measurement -- Resistance - Fuel Pump Coil)

Investigator -- What do you get there?

I get zero zero ohms resistance.

So the fuel pump should be operating.

I am now going to

loosen a fuel line and separately energize

the fuel pump.

To determine if it's a bad fuel pump.

For that I need

(Cracks Fuel Line)

(Whirring)

The fuel pump is work- is is it's pumping but no fuel is coming out of it.

I will next check the connections to the fuel pump.

(Jumps Fuel Pump)

They appear to be tight. I would replace the fuel pump.

STOP -- 10:46 TOTAL TIME TO SOLUTION = 11 MINUTES

EXP 5 -- FUEL PUMP PROBLEM
START 10:11

Try to start the unit.

(Cranking)

Unit cranks but it won't run.
(Cranking)

I'll check to see if we have

ignition.

I'll get that meter again.

(Test Measurement -- Voltage - Points)

Check to see if we have voltage for ignition to the breaker box.
(Cranking)

You have voltage going to the points.

Check to see if we've got it going to the fuel pump.

(Test Measurement -- Voltage - Fuel Pump)

Disconnected the lead going to the fuel pump.

(Cranking)

Have voltage to the pump.

Don't know if we're getting fuel or not.

(Check Fuel Tank)

Ahh

(Cranking)

(Pause)

Hmm.

(Pause)

Check to see if we have ignition to the spark plugs.

Using a (cranking) ----

A spark

going to the plug.

Don't know if we're getting fuel to the carburetor.

Hate to take that fuel line loose.

Make a mess.

(Crack Fuel Line)

Break the line going to the carburetor and see if we have fuel.
(Cranking)

Don't have any fuel going to the carburetor.

I suspect the fuel pump is

(Cranking)

Either that or we don't have any fuel in the tank.

STOP -- 10:15 TOTAL TIME TO SOLUTION = 4 MINUTES

NOV 1 -- FUEL PUMP PROBLEM
START 1:57

Ah I can see it's the emerald one again. My first thing I'm going to do is ah push my start switch, and see what happens.

(Cranking)

Engine cranks uh doesn't want to start uh as I done that I noticed my choke was ah, ah, bouncing around quite a bit, ah, I'm going to try it one more time.

(Cranking)

Nothing. I'm going to check my fuse. Checking fuse. Visually fuse looks good.

Ah I'm going to push again.

(Cranking)

Ok I'm going to check make sure there's fuel in the can

there's fuel in the can.

I'm going to check my ah fuel line, going to my fuel pump ah

this point I would take the fuel line off before the fuel, ah the fuel pump to make sure it is pumping.

Maybe we'll have to use my

I'm going to ah take the fuel line off before

the fuel pump, and check and make sure it isn't plugged.

Ok.

Take a gas bath.

I blew into the, fuel line.

It appears to be
free of being plugged up.

I'm going to do that one more time. It's getting hissing sound out of the tank. I don't know if that was just a breather hole

Ok. Then back up.

Take the gas cap off.

Going to tighten the screw down on top of the gas can and try it one time.

(Cranking)

Ok, this time I'm going to ah

at the fuel pump I'm going to ah disconnect the out

the ah, outline to see if I'm getting fuel

to my fuel pump.

Thinking maybe ah it's not getting any gasoline.

Ok, push the start button.

(Cranking)

Not getting any ah, gas

out of my fuel pump ah

checking my wire connections, to the fuel pump

um.

(Read Schematic)

Thinking ah

check the wiring diagrams ah

my fuel pump ah

fuel pump, the fuel solenoid 3

ah

trying to find it in the diagram

(Pause)

which I can't find.

I'm going to take the control cover off.

While I'm doing that I'm gonna, check my oil.

Oil's ok.

Not getting any ah

gasoline

to my fuel pump.

Going to take the cover off

the control set and check the wire connection

and the circuit board

maybe the brain box isn't telling the fuel pump to operate correctly.

(Removes Cover)

Um

trying to find out where my

fuel pump is at on my wiring diagram.

(Cranking)

(Pause)

Looking at my schematics trying to find

the fuel pump

which is E3.

(Pause)

Ok.

Now my E3

uh to fuel 3, in order to get fuel, K5

only 3 A1-P1, control assembly

Fuse one's ok

K1 start solenoid

A1-P1-3 control assembly to the

T1 ignition coil

Don't know for sure where the

wire goes from the

fuel pump

goes to the P1

A1-P1

A1 being my control assembly.

P1.

Ok.

K1. Let me check my connections on my

(Cranking)

my connec, check my connections up on the

The problem is it's ah

not getting fuel to the fuel pump but not knowing ah

ah

why I'm not getting fuel through it.

Um

something uh electrical I believe is ah

not telling the fuel pump to pump.

Um

Ah not knowing the proper step to take

I looked in ah my prints, my wiring prints, not knowing how to read the schematic ah, not exactly sure where my wire leads to.

Um

(Cranking)

Ah

Investigator -- Ok you've narrowed it down to a fuel problem so why do you think it's electrical?

Well because I, I believe ah, somewhere in the system something has to tell this fuel pump to work. Ah. So it's making me believe the wire connection that tells the fuel pump to work, there could be a problem.

STOP -- 2:21 TOTAL TIME TO NO SOLUTION = 14 MINUTES

NOV 2 -- FUEL PUMP PROBLEM
START 3:30

Ok

(Tries to start it)

Ok, first thing we want do

is check to make sure we're getting fire to the coil.

Ground it.

I'm going to need that jumper wire again.

Check to make sure that we're getting good fire

Ground a wire here

Ok

See what kind of fire we're getting here

Alright

(Tries to start it again)

(Test Measurement -- Voltage - Coil)

We're getting 10.21 volts at the coil

alright,

so let's check and see if the points are opening and closing

(Turns it over again)

It's kind of hard to see there

It don't look like we're getting fire to the points.

See if it's pinched right there

What've we got

(Tries to start it)

(Test Measurement -- Voltage - Points)

We're getting six volts to the points,

let's see

Take the fuse out.

Getting knocked on my butt.

Alright,

got a burned spot on the points,

check the gap

uh, need a allen wrench,

(Examines Points)

What I need to do is set that,

set it up on the top dead center
------to see if they're opening properly

Investigator -- If you do it'll be the same so we will assume you checked that.

Alright

Let's see, we've got ignition,

in a voltage

we're getting

(Tries to start)

(Test Measurement -- Voltage - Coil)

10 volts to the

the coil

That should be plenty enough to start it.

The points look like they were opening.

Well we've come to the conclusion that the points aren't bad, right?

OK

Put the cover back on

Let's start again here

Make sure we're getting fire

Pull the plug

(Removes Plug)

Be sure we're getting fire

(Pause)

Pull the plug out, see what it looks like

Lay it over here, see if we get any fire

(Pause)

(Turns over engine)

Plug's firing

(Pause)

Check and see

if we're getting fuel got fire

Plenty of gas

(Test Measurement -- Voltage - Pump)

There ain't no belt, no pump on it though --------

ok. See if we're getting any fire to the fuel pump?

(Tries it again -- twice)

Ok

(Pause)

(Cracks Fuel Line)

Make sure we're getting fuel to the carb

(Pause)

(Tries it again)

Alright, no fuel

----we not getting, let's check and see if this fuel pump is working

Jumper wire, we'll jump this

fuel pump and see if it activates.

(Pause)

(Fast clicking, or buzzy ringing)

(Pause, hammering, more fast clicking)

Ok, I want to something there

(Tries to start)

(Tries starting motor)

Can't feel it with motor jumping

(Tries starting)

Apparently it's not, there's no gas in it.

The problem it's not getting any fuel

But as for the reason why?

(Pause)

It's not getting any fuel

Either the fuel pump is bad, or it's not getting power to the fuel pump. But, when I hook the wire to the fuel pump, jump the fuel pump, it still wasn't priming itself,

so I believe the fuel pump's bad.

Investigator -- What would you do now?

I would replace the fuel pump,

and then go from there.

Investigator -- Good, faulty fuel pump.

STOP -- 3:39 TOTAL TIME TO SOLUTION = 9 MINUTES

NOV 3 -- FUEL PUMP PROBLEM
START 4:05

Alright, we Onan generator set came, customer don't know what's wrong, it don't run, so first thing I do is see what it does when I hit the start switch.

(Tries Start Switch)

It turns over, I'm going to check the fuse.

The fuse is good.

Put the fuse back in.

Investigator -- Keep talking.

Next thing, make sure I got gas.

(Check gas)

Oh, let's see

Check out make sure we got power

to the fuel pump.

(Pause)

(Test Measurement -- Amperage - Fuel Pump)

Ok, get this on the right reading

Believe that's it, 50 amp

(Turns over engine)

Ok, fuel pump does have power

(Pause)

Next thing, let me check, make sure that the points got power going to them.

(Test Measurement -- Amperage - Points In)

(Turns it over)

Ok, points got power going to them.

(Test Measurement -- Points Out)

See how,

they got coming out.

Show's sparks supposedly coming out.

Pull a plug

(Pause)

See what the spark plug says

(Removes Plug)

(Pause)

Ok, 'm pulling the spark plug out

Ok, next 'm put the plug on, see what kind of spark we have on the plug.

Grounding the plug out against the frame

(Turns it over)

(Test For Spark)

We got good spark

(Pause)

We got good spark, we got power going to fuel pump, now we got to check, make sure that we got gas coming up fuel pump.

(Pause)

Mm. Loose gas line

(Turns it over)

And I would say the problem's fuel pump is bad,

so I would

change the fuel pump.

(Crack Line)

(Pause)

As long as we got gas going into it.

Check the pressure

(Turns it over)

No pressure

(Jumps Fuel Pump)

Well, let me

Check, I'll put a hot lead to the fuel pump.

Now, which one is positive.

Ok, I'm going to hot wire up to the fuel pump

(Fast clicking sound)

Ok, fuel pump seems to be working.

(Pause)

Then I would say my problem is in this fuel pump.

If we've got gas going through it and everything with uh,

hot wire hooked up to the fuel pump we should have fuel coming out.

We do not have no fuel, pumping, pumping through

the electric fuel pump, so I'd say we got a faulty fuel pump or a hose inside the tank which she's not picking up.

STOP -- 4:13 TOTAL TIME TO SOLUTION = 8 MINUTES

NOV 4 -- FUEL PUMP PROBLEM
START 2:15

First thing I do is see if it starts.

(Tries it)

And it doesn't start, so I figure it's either ah ignition or fuel. It's got plenty of battery

Why it don't start

Probably be the first thing I'd check would be the spark plugs

I'd probably check them by taking out the spark plug, see if I get a fire
(Removes Plug)

Investigator -- What do you think?

Well, the spark plug it ain't got no gas on it, so it could possibly not be this at all, it could be a,

just a fuel problem.

Actually as not right now I wouldn't replace this, because it looks like it's alright, and the chances of both of them being bad's pretty thin.

So I think it'll start, and if nothing else it'll run real bad.

(Pause)

Next thing I'd do be take this fuel line right here off and see if it's pumping any fuel up there.

(Removes Fuel Line)

I can tell you right now it ain't getting any fuel, cause that would have leaked out fuel probably if it's getting any fuel.

But I would take a hose, to stick on there and then turn it over and pump it, but I don't want to pump any gasoline out on the

----

Well, it might shoot all over the place

(Tries to start)

It's not pumping any fuel

(Pause)

Next thing I'd check would be check out fuel pump, see if there's any voltage on it

And if there isn't, then it's not necessarily the fuel pump it's something else, it probably is something else.

So right now's when I'd go to the fuel pump, or the deal over there and out how much volts is supposed to be on here, I don't know.

I assume it's 12 volts.

I'm going to assume that it is 12 volts first, since I got a tester here,

and see what I get.

(Pause)

(Test Measurement -- Meter - Voltage)

(Tries to start it)

I'd say the fuel pump's bad

Investigator -- Ok, how do you test that?

Well, I don't know, you might be able to check and see if there's any, see if it's shorted out, but I

there I don't believe.

It shouldn't have continuity, that's what I'd replace fuel pump.

STOP 2:17 -- TOTAL TIME TO SOLUTION = 2 MINUTES

Those spark plugs told the story. From looking at those, because if you got an ignition problem, you're going to have wet plugs, and if you got a fuel problem, they're going to be dry plugs.

NOV 5 -- FUEL PUMP PROBLEM
START 3:20

I'm going to try to start it, see what's what it is I'm trying to do

(Tries to start)

I'll pull the fuse out check it.

(Removes Fuse)

(Pause)

Fuse looks ok.

Putting the fuse back in, if I can get it there

I really don't know what I'm looking for, but I'm hunting

I'm looking at all the connections, to see if they're all together.

Spark plug connections.

they seem to be in good shape.

The coil connection seems to be ok.

I think that I may have found the problem, this coil connection was not down on the coil like it was,

like it's supposed to be anyway

(Tries to start it)

I'm looking to see if it's getting gas

(Tries it again)

Choking it, that didn't do any good.

I'm leaving the choke open

(Tries it again)

I thought it was flooded but I don't think it is.

I'm looking over the carburetor, see if I can find anything wrong with it.

Checking the fuel line, I don't see anything wrong with it so far.

Wire connections under the fuel pump.

I do not know what this thing is, but I'm going to attempt to take it off to see, I know that there's wires underneath of it.

(Pause)

(Removes Choke Cover?)

There is a loose wire on this.

Going to tighten it up.

(Pause)

Got it tight, I want to make sure it's not shorting against something.

I'm going to try to start it again

(Tries it)

Evidently that didn't do it.

going to put the cover back on it.

Got the cover back on, starting the nut on it now.

I don't smell any gas, it doesn't act like that it's getting gas,

or like it's overloaded with gas.

(Removes Air Cleaner Cover)

Take this cover off of this, see if I can smell any gas.

I don't see any gas at all coming up to the carburetor.

It acts like that it has no gas in the carburetor.

Either the electric fuel to me seems like it's not pumping the gas, or the fuel pumps bad, one or the other.

The only way that I know how to check that gas line is to, you know, crack the gas line.

(Cracks Gas Line)

See, I guess the best place to take this apart would be right in here.

(Tries it again)

I have no gas

(Tries it)

No gas coming out of the fuel pump

into the carburetor.

See if we can find out if it's the fuel pump or we got something loose on it.

I'm going to take the front off this housing here and see if I have a loose wire or something inside of here.

(Removes Control Cover)

Take the front off and look at the electrical system here,

see if I can find anything wrong in there.

It's kind of an on and off switch on the side here, I do not know what that's for, but it is on, to I'm assuming that the,

that it is for the generator. I've got a plug here for something that I do not know what that's for either.

(Pause)

Let's see if I can turn this off and turn

(Pause)

Investigator -- What are you looking for?

I think it's got a loose connection, is what I'm looking for.

But, I do not see that either.

Look at the schematic here just a second.

(Schematic)

(Mumble)

This schematic doesn't have any numbers.

These are what?

Investigator -- That's the parts list.

Ok.

(Pause)

I'm looking at the schematic, trying to find the

fuel pump is what I'm looking for.

(Pause)

And I haven't found it yet.

(Pause)

OK, I do not understand this wiring diagram.

I found the E3, but I do not know what it goes to.

So I don't know what I'm looking for anyway.

(Visual Inspection)

Take one more look and see if I see anything else that is wrong with it,

that I can see.

Nope, not that I can see.

(Pause)

Ok, at this point I'm pretty well stuck.

STOP -- 3:32 TOTAL TIME TO NO SOLUTION = 12 MINUTES

EXP 1 -- WIRE PROBLEM

START 11:14

Well, I've hit the start switch,

I can feel the fuel pumping so I know
that I do have voltage to my fuel pump.

Therefore, that means my circuit board is good, am applying voltage, so what I'm gonna do next is see if I have it at the starter.

I, in case there's a dead sh, short somewheres.

Ok, like I said previously I've hit the start switch, I can hear the fuel pump pumping, I've got my hand on there, I can feel it vibrating, so

at this time I know I least to that, that means the fuse is good,
and it gives me a pretty good indication that I do have battery power

at this time don't know if it's adequate enough, because of the fact that the fuel pump draws less current than the starter does.

So what I'm going to do next is move over to my starter terminal itself.

(Test Measurement -- Voltage - Starter)

Putting it in the 50 volt range, so I'll cover the range of 12 volts which I want to measure at the starter

input post

(Clicks)

Hitting it I find I have none.

(Removes Cover)

I know I got voltage to one side over here. My next step would be to take and disconnect the battery power and pull out the control panel so I can get right in at the solenoid terminal and see if the solenoid is energizing or

maybe it does have voltage but it could be that the K1 itself is not pulling in to crank the unit.

we'll halfway plug it on, stick a probe down in there and see what we get

Alright, we're getting 12.37, 12.38

(Clicks)

Alright, it don't drop

here

At the connection

(Clicks)

So my assumption is the PC board is bad

Investigator -- Ok, so you replace that and you still have the same problem

If you replace the board, they'd still have the same problem.

Ok, so what you're saying the board is not bad.

Investigator -- The board is good.

Ok, ok, let's see here then.

See if our solenoid is activating properly

We're getting one volt at the solenoid

(Test Measurement -- Voltage - Solenoid)

(Clicks)

Ok,

we've got 12.34 on one side of the switch

(Clicks)

or we got a bleedthrough

(Clicks)

Mhmph

We're not getting anything here.

(Clicks)

We got this wire, ok, going to the board

We've got these going to the board.

Let's see this jumper wire,

I'm going to jump the solenoid and see if it's activating

(Pause)

-----away,

before we can get to it.

See if this solenoid will activate

on it's own

(Loud noise)

(Jumps Solenoid)

Eah.

the solenoid's good,

so our problem is between this

Ok, we go

through that board

back up here,

I don't think the

He was telling me about a wire, but I can't remember,

I don't believe
that it was crossed, but I can't

So next I'll have to disconnect the battery power

(Disconnect Battery)

I've got the control panel tilted at a slight angle now where I can get the meter at

leads back on the control panel, making sure it won't short out against anything now, I take and reconnect the battery cable.

(Test Measurement -- Voltage - K1)

Now I go to the S terminal on K1 to make sure we're having B+ applied to this, to pull in first of all.

Hitting the switch, and I find out I have none.

So my next step is to disconnect this cable again because I will be unplugging the control board, and when you do that, if you leave the battery cable hooked up, when you disconnect the plugs it can cause arcing at the

contacts.

(Schematic)

I'm referring to my diagrams, 611-1174, and looking at this diagram I find that coming out from my connector plug I should be

getting voltage from pin 2.

First of all I'm going to disconnect this plug from the circuit board, making sure

the contact is in there,

and they have a tendency to take and from use get bent up a little bit, make sure it's latched in there, good,

making sure also the pins are in the right location.

(Visually Inspect Pins)

Find P1, and here is P1-2,

it seems to be latched good and everything like that,

so I'll take and reconnect it now, verifying that it was Ok, bearing in mind I already know that the B+ is at this board because of the fact that I have voltage to the fuel pump.

So I come to terminal two at my connector plug with a small probe. There's access if you got the circuit board away.

I got it carefully on there, making sure the board is locked so I don't short any B+ out, and I hit the switch again.

(Clicks)

(Test Measurement -- Voltage - P1-2 - K1)

I have voltage here.

Ok, so I go back down to my solenoid and reverify, there is nothing.

So it gives me one indication.

I got at my board but not at my terminals, so it probably indicates the wire or a bad lug.

So again I pull it off the circuit board, disconnecting the plug after I've disconnected the battery cable.

I disconnect the lead at the solenoid here.

Now with the battery disconnected, I'll take a resistance check to see if there's a bad wire.

(Test Measurement -- Continuity - P2 Wire)

I zeroed a meter, eliminating all meter resistance, and air, so the reading I'll read will be the strictly the circuit's reading.

And I find a wire is open from pin 2 to solenoid.

STOP -- 11:2O TOTAL TIME TO SOLUTION = 6 MINUTES

EXP 2 -- WIRE PROBLEM
START 11:06

First of all make a visual expec- visual inspection on the outside,

make sure that there are no

real obvious

things that would cause the problem

Check the oil

(Pause)

(Check Oil)

Oil seems to be adequate.

Preheater is in the summer position

Ok

I'll start the set

(loud clicks)

Ok, from the sounds of things we have

we have B+ going to the control,

sounds like there's B+ going to the fuel pump,

if B+ is going to the fuel pump it should be going to the coil.

What we're not getting is we're getting it, the engine is not starting.

It is not cranking, excuse me.

Start solenoid possibly, starter possibly, so I will check those two things first.

(Pause)

(Remove Control Panel)

Taking the front cover off.

Ok, the first thing I'll check

is to see,

and I suppose I wouldn't have needed to take the cover to check this,

check and,

check and see if there is B+ going to the starter

during cranking

(Test Measurement - Voltage - Starter)

I'm checking DC voltage at the at the starter.

(Clicks)

Ok, there is no voltage at the starter.

(Test Measurement -- Voltage - K1)

Next I'll check the B+ going to the start solenoid itself.

Ok

(clicks)

Oops.

That's not going to work, let's try that again.

(Clicks)

There is no B+ going to the,

to the start solenoid.

Um

I guess

if there is no B+ going to the start solenoid and the only way that B+ can get from the start solenoid

to the board, or to, from the from from the battery to the start solenoid is through the board.

I guess I would assume that there is a problem either with the board or the connections.

(Pause)

And check out the pin.

(Pause)

Investigator -- And what pin are you checking?

(Test Measurement -- Voltage - P1-6)

Uh, I'll have to check out pin P1 ssss, P1-6, and also check out P1-2.

P1-6 shows 12 volts, so we've got 12 volts going into the board.

P1-2, when we press the starter, press the start switch shows

12 volts,
Ok

I'm connected up now to the end of the wire that comes out of P1- 6 and press the start button again (clicks) and we get nothing, so

there's a problem maybe with the pin,

or the connector,

Or the wire.

Bad connection?

(Pause)

I'm uh, got the

the meter probe on the wire,

and got to have it plugged in.

(Clicks)

And I'm getting nothing, so I assume that the

the connector is bad,
Is that correct?

Investigator -- Keep checking.

I can check for continuity.

And it's open.

STOP -- 11:15 TOTAL TIME TO SOLUTION = 11 MINUTES

EXP 3 -- WIRE PROBLEM
START 11:08

Doesn't crank huh.

OK.

I gonna measure the voltage to the starter.

I got a feeling there isn't going to be anything there.

(Test Measurement -- Voltage - Starter)

Nothing there. Fuel pump runs. So

now we've got to find the start solenoid.

Which if I remember correctly is in here.

(Removes Cover)

(Schematic)

Investigator -- OK. What are you looking for?

Coil to the start solenoid.

------.

(Test Measurement -- Voltage - K1)

So I'll measure voltage to that while I try to crank it.

(Cranking)

Which it doesn't get any.

Which comes from

A1-P1-2.

A1
P1

2?

Looks like that could be it right there.

So measure voltage on that.

(Cranking)

Got voltage there

kinda.

(Cranking)

Looks like a pin connection

or something along those lines.

(Cranking)

Interesting.

(Cranking)

Maybe I only saw voltage there uh.

(Cranking)

Hm.

Investigator -- What are you doing now Kevin?

I'm looking at the board and thinking.

Investigator -- Say it out loud.

Don't know why I measured it once and I measured voltage there and now I don't.

That's what's got me st- buffaloed.

(Cranking)

There's nothing there. OK.

So

we don't get any power out of A1

P2 to pull in the solenoid

but everything else runs.

I'm going to take the board loose and look at that.

If I can get the fuse out.

Just for something to do.

(Removes Board)

Investigator -- What are you looking for?

(Schematic)

Fuel pump.

E3

K4's got to be closing to run the fuel pump.

That one is any way.
But that one isn't.

Maybe that wire's missing, I don't know.

Won't know until I look at the board.

You didn't cut the wire off the board anyway.

That I can tell.

Looks alright. I didn't say it was.

Investigator -- What are you looking for?

Nothing right now. I'm thinking. Devising a test.

To see if those contacts are closed. I don't know whether I trust this connector here that much.

(Test Measurement -- Voltage - P1-2)

(Cranking)

Wish I had a better probe.

(Cranking)

Strange.

Investigator -- What are you getting?

I'm getting it on that side but not this side so it looks to me like this connector doesn't work or something.

On the right pin? A1-P1-2.

This is a bear to do you know it?
(Cranking)

There's 12 volts there.

This plug's no good.

Cause I don't get it here.

(Cranking)

Investigator -- What's the problem then?

Well

see if I can make it work.

I don't think I can get this on here.
You're getting your 12 volts pulling your start solenoid right there.

But you're not getting it

Investigator -- So what would you replace then?

Well I guess I'd try to fix the connector first before I'd replace anything.

This thing here. Pull this out before I blow something up. Too many wires especially the ones I'm wearing.

(Test Measurement -- Continuity - P2 Wire)

We'll check resistance of the wire.

Which is open.

This wire's open.

STOP -- 11:21 TOTAL TIME TO SOLUTION = 13 MINUTES

EXP 4 -- WIRE PROBLEM
START 10:28

(Whirring sound)

Sounds like we've got a dead battery.

So I think the first thing I'll do is I will check the battery voltage.

(Test Measurement -- Voltage - Battery)

And I can do that.

Volts.

(Whirring)

Oh that's just the fuel pump that's operating.

So I'm going to take the cover off the control box

and look at a wiring diagram.

(Schematic)

K1 must not be energizing.

Investigator -- Make sure to say what you're looking for.

I'm looking for the K1 solenoid and what causes it to energize.

Let's see that comes off of pin 5

so it's P1-5.

Find that on the schematic here.

No

it's P1

P1-2

not 5.

Ok so it could be

well

so I'm going to check to see if I'm getting voltage to the K1 solenoid.

(Remove Control Cover)

Ok in order for the K1 solenoid to operate we have to get B+

to the switch terminal.

So I'm going to check and see if we are.

(Test Measurement -- Voltage - K1)

(Whirring)
And we are not.

So that voltage comes from

A1-P1-2.

(Schematic)

So I will check that point next.

(Test Measurement -- Voltage - A1-P1-2)

(Whirring)

I am getting it to the connector.

(Test Measurement -- Resistance - P2 Wire)

(Whirring)

So I'm going to check with an ohmeter to see if the wire was open.

Probe is too big.

I would say the wire's open.

STOP -- 10:34 TOTAL TIME TO SOLUTION = 6 MINUTES

EXP 5 -- WIRE PROBLEM
START 10:08

It sounds like the fuel pump is pumping but the engine won't crank.

I don't know

check to see how the battery condition is.

(Test Measurement -- Voltage - Battery)

Got 12 volts.

I believe we've got

(Test Measurement - Voltage - Starter)

Check to see if we have voltage going to our starter.

(Press Switch)

No B+ going to the starter.

It would appear as though the start solenoid is either defective or the wire isn't connected. I'd have to pull a control panel off. Check

(Remove Panel Cover)

Take the fuse out of the control box.

OK I got the panel loose and I see right away that the

the wire going to the S terminal on the start solenoid has been damaged.

Check continuity to make sure.

It's from P1-2

Have an open wire from P1-2 to the start solenoid S terminal.

STOP -- 10:10 TOTAL TIME TO SOLUTION = 2 MINUTES

NOV 1 -- WIRE PROBLEM
START 1:30

I'm looking at the Onan gen set emerald one

uh first thing I'm going to do is see if it'll start.

We'll push the start button.

Ah

I get nothing.

Um

I'm just gonna kind of look around

take a look at it for a minute.

I can see a switch on the side.

I'm not sure what it is. I just switched it off.

I'm gonna try it one more time.

Still does nothing. I put it back on on.

Ah I'm gonna step around the side uh

over here to the starter.

I'm gonna try and hear where the

sound is coming from.

One more time.

Ok it don't sound like it's coming from the starter.
Ah

out of curiosity I'm going to pull the

the fuse.

Fuse is ok.

Let's see.

Um

Still lookin. I'm confused already.

Push the start button again.

I'm gonna listen for a while try to figure out maybe exactly where the sound's coming from.

Um

I'm not sure.

First thing I'm gonna do is check my ah my connections

battery wise

check the battery first.

Investigator -- Battery is good.

Battery is good.

Uh connections

up from the battery.

Ground appears to be good.

Check the positive.

Connections are good down here.

I'm gonna connect or check the positive connection.

You just take the uh

control

plate off.

(Remove Control Plate)

Investigator -- Keep talking.

Ok I'm checking ah

my connection

from the battery my positive lead.
Connection seems to be good.

I'm checking my connections on my

oh boy here I ah

touched uh my control my circuit board ah

and it acted like it was grounding out

um so I'm thinking I have a bad connection somewhere.

Can I

does that hurtin that if I touch that down there I mean I got some

thinking I've got ah

a bad ground.

Ah

checking my ah

starter ground.

Checking my connections

inside.

Checking my wire going to my starter.

Checking my connections.

Inside.

Investigator -- Keep talking.

Um

not sure what my problem.

Out of curiosity I'm gonna check my oil.

Maybe my ah

my oil is low.

I believe my oil is gonna be ok. Was thinking maybe that low oil shut off.

Oil's ok. To where I don't think it was causing my problem.

Um

wondering if maybe my problem is in my ah

start stop switch

connection.

Everything

connections seem to be good.

I'm ah

disconnected a wire off the start button

getting the same sound so I'm going to trace this

this wire

to where the connection is away from the start stop button.

Too many wire clips can't tell where it goes.

Tracing the wire.

Found one

that goes to a plug on the back side.

Thinking maybe there's something that

isn't

plugged in.

Maybe missing a part.

Um

Investigator -- Keep talking.

Thinking maybe ah

I have a part uh

thinking maybe I have a problem on my

ah control circuit board

ah

visually checking the circuit board to see if maybe something is blown.

Visually looking and I don't think so.

I'm gonna take ah

do you want me to you don't want me to guess on a problem?

Investigator -- If you think you have an idea say it.

I'm thinking ah guessing maybe the the start stop switch is the faulty switch.

Incorrect?

Investigator -- Ok. Well can you check that?

Um

going to ah

um look for a minute ah

Going to ah

(Pause)

Confused.

I know you want me to talk but ah

kind of at a stalemate right now.

Um I'm thinking in my mind right now that if the

ah start stop switch is defaulted I wouldn't be getting anything.

I'm looking

trying to find the sound more direct.

Um checking connections.

Disconnecting wires trying

Don't have much experience with the emerald

so a lot of this is new to me so I'm not sure

Looking around I'm na

Investigator -- Ok the start switch is ok.

Start switch is ok. I'm gonna connect switch back.

Um

(Clicking)

Checking the wires to my circuit board.

Ok I'm going to

check my wires that go to my

my points

to my coil

check the connections

connections to the coil on the positive side appear to be good negative side ok.

Going to ah

Checking my points.

Condenser, points appear to be

Push the start button again to inspect my points.

I think that's my problem. This time I feel my problem is

is down

by the

control box.

(Clicking)

Still looking for a connection that may be bad.

Connections seem to be ok.

(Clicking)

Trying to pinpoint the sound ah

(Clicking)

Ah

going to look at my book maybe me look at the ah wiring diagram

hmm
checking uh

the start stop

(Read Schematic)

Number uh check my ah

See where the wire leads go to.

Switch, Start, stop, switch, battery charge, generator

Investigator -- What are you looking for there?

I'm ah just reading through my ah parts list

gonna read what ah

K5 K5 is a relay.

Relay switch, check a couple of my wire leads that go.

Looking at one two three four five six eight wires that go to

seven wire goes to the ground, eight wire goes to ground.

Checking them switches.

Seven wire, eight wire are both

to making good connection.
Six wire goes to the

battery. K1 start solenoid goes to ground.

Six wire six wire tracing six wire. Appears to be making good connection. Six wire thinking maybe the start solenoid could be bad I'm going to check the wire connections.

Five wire

four wire goes to the points I believe the points are ok.

Four wire.

Three wire

goes to the ignition coil.

The coil I believe's ok, checked earlier.

Two wire, goes to the starter solenoid.

check the connections

connections to the coil on the positive side appear to be good negative side ok.

Going to ah

Checking my points.

Condenser, points appear to be

Push the start button again to inspect my points.

I think that's my problem. This time I feel my problem is

is down

by the

control box.

(Clicking)

Still looking for a connection that may be bad.

Connections seem to be ok.

(Clicking)

Trying to pinpoint the sound ah

(Clicking)

Ah

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hmm
checking uh

the start stop

(Read Schematic)

Number uh check my ah

See where the wire leads go to.

Switch, Start, stop, switch, battery charge, generator

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Three wire

goes to the ignition coil.

The coil I believe's ok, checked earlier.

Two wire, goes to the starter solenoid.

That was the, two wire.

One wire goes through a resistor.

This time I'm going

not knowing how to ah check, I'm going to ask if the starter solenoid is faulty.

Investigator -- It's fine.

(Reads Parts List)

It's ok. (Laughs) ah bad guess.

Ah I don't know.

I'm going to read down through the parts list. Um, thinking my start stop switch is ok.
Ah to my solenoid wire or to my solenoid, starter solenoid connections are ok there.

Um start stop switch is ok. Um battery ah positive side to my solenoid connection is ok.

I am going to

um

checking my ah

(Pause)

Investigator -- Ok why don't we quit here on this.

STOP -- 1:55 TOTAL TIME TO NO SOLUTION = 25 MINUTES

NOV2 -- WIRE PROBLEM
START 2:45

Check the fuse. Ok?

Fuse looks good.

Put the fuse back in

We'll see what it does

(Clicks)

Ok So what I need to do first is load, check the battery to see how much voltage it has in it

Investigator -- The battery is fine

Ok the battery is fine

Ok so now I need to check my wires to make sure they're not crossed

Ok, as we look in we've got

the positive wire going

to the back side here, the solenoid

And that should go to

the

Let's see

That is the negative, ok. Going to the table uh oh we got hung here alright so the wire is correct there, so what I need to do is pull my cover

(Removes Cover)

off my panel

to see if the wires are crossed

on the solenoid

(pause)

Ok, well

Take the fuse out

alright, getting the screws out

This is interesting, you know that (laughs)

Ok

(Pause)

(Reads Schematic)

Alright,

we've got

a K1 circuit

K1, that's right

Ok,

we've got,

what do we got here?

(pause)

----------battery

Hmmh

(Visual Inspection)

That's K1

Ok

Everything seems to look alright

(Trace Wires)

Put the control board back in

Ok,

check the cable on the starter

It's tight

coming acrost

to the solenoid it's tight there.

Ok.

I believe it's got to be in that start circuit

Put the fuse in here

(Reads Schematic)

I've got

K2 1 S1

I need to, to look at, see how the starter switch is wired

so I can make sure that it's on properly.

We got S1 in the middle

Let's see

And we have S1 in the middle, ok that's right

With remote,

ok where am I

Alright, that don't show it

We need to see if our two wires are crossed, so

we need to look at,
see where

(Looks in Index Of Service Manual)

Electric starter will be 6-27

(Pause)

(Looks Up Starter)

OK

(Pause)

Let's see where it says remote------

the ignition system

Control operation 7-2 OK

Let's see if it shows the switch

This one

This one,

hmmmh

This one's the switch

We got S3 on the stop

------start side

S1-2

Ok, we got S1-3,

S1-2,

S1 ok.

1

2 should be

2 be on the stop side of the switch

(Reverses Switch Contacts)

(Pause)

---S1 in the middle

S1   S3

here

(Pause)

OK, see what happens.

Put the screws back in, 'n hold the cover on

(Pause)

Put the fuse back in

(Test)

Nothin

Ok

I'm gonna try somethin here, might have the two mixed

Pull the cover back off,

take a look and see here,

I got

---B start on ----

(Reverses Wires Back)

Start should be

S1-3, S1-3

start position

Ok, switch ------ Ok

--go there S1-2

S1-2 on the other side,

S1 in the middle

like so OK,

we need to see something.

Get the meter and see

what kind of voltage we got going to the starter

(Test Measurement -- Voltage to Starter)

Well,

I'll first check the solenoid

(Test Measurement -- Voltage to Solenoid)

OK, set it on ohms

Alright we want it on volts

Let's see

I don't understand this meter too well

Ok, I'm going to try it anyway, see what I get

(Test Measurement -- Voltage - Solenoid)

Ok, I got 12.4O to solenoid, ok,

Now I'll see if I have a voltage drop when

I'll try to start it

Cause it will not start

(Clicks)

Ok, we've got a wiring problem

We've got a ground here

and we'll check it,

see what kinda ------we got on the starter

(Clicks)

(Test Measurement -- Voltage - Starter)

Ok, we're not getting any voltage to the starter,

so

there's got to be a problem right here.

We need to check to the starter system.
Alright we got

S2

(Reads Schematic)

Let's see, starter solenoid P1-3

P1-2 Ok, we got

P1-7, P1-8,

where does P1-3 go?

P1-5

And, what is that?

P1-5

Ok,

so you got the starter motor,

from the starter motor to the solenoid,

let's see

Mmmmm

One here P2

(Whistles)

(Pause)

(Checks Index)

Check the front, the primary,

see if we find the starter system

fuel, electric starter.

tools, preparation, troubleshooting,

it's 51,

Let's see what say in there

Service, troubleshooting, torque specifications, --------, primary systems 61 61,

see what they say, Engine misfires, engine backfires,-------- surges.

I don't anything on that, Ok,

check the wiring schematic,
find our circuit, start-stop Solenoid we got,

What've got, we got S1 offa here, ok

---P2, P1-2

-----Ok

What I need to do is pull this cover out of my way so I can see what I'm doing here.

(Traces Wires)

And we got P2,

OK P2

Alright, that's solenoid,

it's a battery

2, we got S

-----24, 5 to the back over there.

Uh huh

What is that?

Ok,

P1 to K1 start circuit goes to there,

unless this solenoid's not any good?

See if it's activating

Put the cover back on

(pause)

-------back in
and the fuse,

check our solenoid.

Ok

--------that back there

-----that

So we can get this all hooked up

(Test Measurement -- Voltage to Solenoid)

(Clicks)

Ok, we're not getting voltage to our activator solenoid.

Uhh, is that starter wire hooked up?

------ Where's it going?

Can't see.

(Reads Schematic)

Yeah, it's hooked up, ok

----to the solenoid,

number two up to

Alright, if I'm reading this schematic right, these two wires are crossed.

These two, this wire should be

This one should be over here and this one should be here?

Investigator -- They are on there correctly.

(Reads Schematic)

Alright got a problem somewhere, let's see,

S1-2

Eh, you don't have a diagram on just what the deals on the schematic, do you, what they mean? Like

this would be the remote, correct? From you S1 should come over

Investigator -- Here's your parts list

Ok, switch, starter, stop

Ok, so that is not even my starter solenoid then

K1 is starter solenoid Ok
We got, ok, starter solenoid we got the battery, coming to number six.

1 2 3 4 5 6 ok that's right, that should on number 2, that's right

only plugs in one way

Ok, we're not getting any voltage at the battery.

Ok (Pause)

(Clicks)

Ground

(Pause)

Ok, I got a good connection here,

I got a good ground

uuuh got a good ground

I guess that's gotta be a good ground

Let's see, if I got,

see if I'm getting twelve volts to my switch

(Test Measurement -- Voltage - Switch)

Let me check this switch real quick

If I'm getting, let's see

I'm not getting it on this side

(Pause)

Ok, let me check something here,

I've got

hot wire on the switch

Alright, that hot wire,

should it go in the middle, and not on the end

Let's see what happens.

I'll put that on there

(Clicks)

Nope.

So

Ok, that's nothing

(Pause)

(Read Schematic)

That don't register.

Now see that's S1-3,

S1-3

Eh remote

got a fuse, got a starter, got S1

S1 should go in the middle

Ok

Go in the middle

S1 in the middle

Alright

we got,

where's our switch, S3, S2

S1-2,

That would just make the switch work backwards

It should, anyways

Let's see

Should have---

Yeah, ok

The switch is right

And we got a problem from the switch

to the solenoid

---let's see

(Pause)

(Switch Not Pressed)

I'm not getting a reading

Alright,

ok I'd better put the fuse back in

----get no power,

check it again,

12.39, ok could it be on the start side of the switch?

(Clicks--several sets)

Mhm,

I don't believe that runs through that printed circuit board on that K1 circuit,

it should be after it runs on that.

We got

--- to the remote.

Could be a,

could this circuit board be bad?

I'm not sure on how the voltage runs through this board, if the voltage, from what I'm seeing,

I'm not getting the voltage, when the once I put the load on my switch, my board is failing. Ok?

I don't know if the voltage travels to this K1 circuit,

I mean it, this uh, this circuit board or not?

I can check, hang on just a second.

Let's see something. If it fails on the other side of the board

(pause)

That should be,

the hot side should be number six

Let's see we ain't getting it there.

They got a protective cover on it, well that just don't fit inside there.

1 2, 1 2 3 4 5 6,
alright that should be a hot lead,

right there

But it's not

uuhh

Let's find that

----board here.

We got

this one right here should be be 12 volt

ok, it is

Alright, we'll go

(mumble)

---to there, to

right there

Ok,

now to see if it fails

when we hit the start button

Got a ground here

(Pause) (clicks)

Investigator -- You're off the ground when you push that switch

Ok, let's try it

We're not getting, something's failing here,

I think it's failing before it even gets to the board.

I think that'll carry a ground, let's see

Nope

I'll put us a jumper wire on the ground here, so we don't have to try to get underneath there

(Pause)

Clamp it to the motor base,

see if we get it.

(Pause)

Mm, no we're not getting a good ground.

Move it over to this bolt.

to the table, see if we get it now

Nope, still --------

Can't travel through this paint

Get it over here on the cable

I know it'll go through there

Ok

Pin number six

Let's see, there there there,

right there

Ok

(Pause)

----put it back up,

check our lead

We're not getting,

maybe

minus

voltage.

I'm going to plug it in to the board.

We got

12.37 unplugged,

we'll halfway plug it on, stick a probe down in there and see what we get

Alright, we're getting 12.37, 12.38

(Clicks)

Alright, it don't drop

here

At the connection

(Clicks)

So my assumption is the PC board is bad

Investigator -- Ok, so you replace that and you still have the same problem

If you replace the board, they'd still have the same problem.

Ok, so what you're saying the board is not bad.

Investigator -- The board is good.

Ok, ok, let's see here then.

See if our solenoid is activating properly

We're getting one volt at the solenoid

(Test Measurement -- Voltage - Solenoid)

(Clicks)

Ok,

we've got 12.34 on one side of the switch

(Clicks)

or we got a bleedthrough

(Clicks)

Mhmph

We're not getting anything here.

(Clicks)

We got this wire, ok, going to the board

We've got these going to the board.

Let's see this jumper wire,

I'm going to jump the solenoid and see if it's activating

(Pause)

-----away,

before we can get to it.

See if this solenoid will activate

on it's own

(Loud noise)

(Jumps Solenoid)

Eah.

the solenoid's good,

so our problem is between this

Ok, we go

through that board

back up here,

I don't think the

He was telling me about a wire, but I can't remember,

I don't believe
that it was crossed, but I can't

be sure, we got grounds

on top, ok, they're both right.

On the bottom,

we got P1-5,

let's see

Let's find this

go

Starts on the solenoid,

ok, we got

Now that's that transformer

-----------that's the ground bar,

to here

That's AC,

CR-4

negative plus,

negative plus

Ok, that's right.

that's S2, S5,

Ok

what've we got here.

We got P1-1

P1-1

Alright, that's not on the start circuit.

Ignition

S2, P1-4

4

(Pause)

Alright,

that's to the points

Five

goes up there

P1-7 P1-8,

7 on the top, 8 on the bottom.

I don't guess that would matter too much.

I'll try it.

Plug 7, we had 7 on the bottom, 8 on the top

Board shows 7 on the top, 8 on the bottom

Ok, it really don't matter anyway, that's a ground but just checking it.

Ok, that's 6 going to the battery side of the solenoid.

162, the battery side of the solenoid

78, that's 5

4.

14 to the oil pressure shutoff switch.

That would be that

P1-3,

P1-3

11 12, 13.

I'm not going a -----?------.

(Pause)

Ok

(Pause)

Try this switch again

We got P

Let's see here

I'll check these connections on these

Well, they're right or they wouldn't be tied together

-----------it's 1 2

(Pause)

Let's see if we can find this switch diagram in here

'cause that's, that's got to be in that

switch

between the switch, and the starter

Ok, let's see

(Reads Service Manual - Does Not Crank - BGEL Section)

-------troubleshooting----------ignition system, 68

------68,

alright it don't show wiring on the starter switch eh, ---628 that one just, think it just shows the starter,

------ ok

Control,

B G L E troubleshooting, 711

Go there, that one engine does not crank

Ok, if engine cranks the set but not remote panel failure to

Ok

(Read)

If engine cranks at remote, alright, expects your voltage cranking due to battery not charge, terminal collections loose or dirty

If one is open, connect the voltmeter between S2 -------starter solenoid and ground check for battery voltage when S1's placed in start position (mumbling) ------- is due to

K1 relay not grounded defective K1 starter

The PC board, ok, we need to check

the S terminal on the start solenoid

and the ground

Let's see what we got Ok, we to take the jumper wire, and hook it back up.

Plug it to a ground

Ok, I'm dropping these screws everywhere

(Read)

Connect the voltmeter between the S on the starter solenoid and ground. (Read)

Check for voltage when S1 is placed in start position.

(Pause) (Clicking)

------plug back in, alright, we got

----that's there, that's there

Ok, now

(Pause)

(Test Measurement -- Voltage - S1)

Ok, ---------check for battery voltage when S1's placed in

------ ok

(Read)

(Clicks)

No battery voltage

(Clicks)

but we also don't have the battery voltage going through the switch

(Clicks)

Ok,

if voltage is not present as described in step 5, fault is due to open circuit on the K1 and PC board

Ok, check for continuity, and correct if ---?---- is open.

Ok,

----we're not getting voltage through the switch,

we got voltage at
12.34 on one side,

we got the start side and we got

not even a half a volt.

Alright, let's check the switch and see if it's good.

Investigator -- The switch is good.

(Reads Manual)

The switch is good.

Ok,

so we need to check for continuity

and correct if circuit is open

(Test Measurement -- Voltage - PC Board - Solenoid)

But we've got

12 volts at the board

12 volts at the solenoid

If we can check this wire and see if it's broken, but I doubt that.

See if we're getting

it through the solenoid.

Let's see, we go here to here

(Clicks)

Ok, we had it now I lost it.

I got 12.10 here.

So that means it's going through the board.

So I need to check my wire and see if it's shorting.

(Pause)

Ok

(Pause)

(Test Measurement -- Resistance - P2 Wire)

Ok,

I show no resistance

on the wire.

at all.

Because the wire don't have any wire on the end of it.

STOP -- 3:30 TOTAL TIME TO SOLUTION = 45 MINUTES

NOV 3 -- WIRE PROBLEM
START 4:15

(Tries To Start Engine)

I'm going to hit the start and stop switch, see if it turns over.

Does not turn over

First of all I would want to check the voltage in the battery,

see how many volts it has

Investigator -- Battery's good

Ok, battery's good.

Got the problem other than that.

(Test Measurement -- Resistance - Fuse)

So let me check my fuse, make sure my fuse is good.

Fuse looks good, but we'll make sure with ohmmeter.

Fuse is good.

Going to pull off the front control panel

-----remember. Let me check the starter leads out first.

Difference between these and the BGA model or the other models I been working on

Ok

(Pause)

(Test Measurement -- Voltage - Starter)

Ok, I've got the leads hooked up, one to the hot lead on the starter, gonna check for

output, er charge into the starter.

Do not have nothing there, I would say the starter relay is bad.

Checking that next.

Pulling the cover off the control panel

(Removes Control Cover)

See what we got here, alright, uh

(Test Measurement -- Voltage - Solenoid)

get the ohmeter back in here, and check and see what we have going through the starter

relay switch.

Alright,

find good ground for this

Ok,

hit the starter switch again

(Soft clicks)

(Reads Schematic)

let me check the wiring diagram to make sure, but I think the starter switch is still bad.

Ok, see what we have

------the schematic,

see if the switch is wired right

(Pause)

Breaker

let's see

(Visual Inspection)

Checking the leads, leads seem to be ok.

Ah, let's see what we got back here.

Lead seems to be alright.

Under normal circumstances, what I would do would I would be jumping the starter switch acrosst, I don't know if I can do that or not though.

Ok, then back to this, let me fix this up before I do anything.

(Pause)

Mmh. And I don't think I will.

Ok, let me get in here

(Pause)

K. Got a hot lead hooked up to the starter switch.

And I don't believe that would be it.

(Jump Starter Solenoid)

Ah, best thing is, I guess going to have to trace the wires out, there's going to have to be a wire or something wrong here.

Ok, this one

(Trace Wires -- Switch to Starter)

(Pause)

See what we got.

Investigator -- Keep talking.

Alright, well let's see, I'm just looking at the wires, trying to trace out some of these wires 'n

Never done this before so 'm,

new to me.

'n trying to trace out the wires for the switch to the

starter

(P2 Wire Came Loose)

Ok, got a lead out here, maybe that's it.

Let me poke it back in.

(Pause)

(Pin Connector On Backwards)

Ok, let me try that.
Nothing there now

'M ok, still nothing Let me check the fuse, see if I blew it.

Fuse is good

Put the ohmmeter back here

(Pause)

(Test Measurement -- Voltage - Switch)

Ok, I've got voltage there

I still don't have nothing into the fuse, into the start-stop switch

Whatever I did, I

went backwards

Checking the leads again here.

Mm try it again.

Still nothing

See what happens when I

find a good ground here

(Pause)

Well, at this point I would

have to put in a new switch, I think.

Investigator -- Is that what you'd do?

Yeah, I'd have to put in a new switch. I either shorted it out myself, or the switch was bad.

Investigator -- The switch is good.

Ok, a new switch is put in, I'd have to keep looking

(Laughs)

Keep tracing these wires then.

Take 'em one step at a time. Start-stop,

S battery plus, battery minus

(Reads Schematic)

Lets' see, solenoid

(Pause)

Investigator -- Keep talking.

Ok, and just trying to go through this wiring diagram.

Little bit of Greek to me, but huh I'm trying.

well, my next bet would be saying that this board might be bad,

but I have no way of testing it out.

Only thing I could do would be to replace it with one that I know is good,

and go from there.

So,

right now at this state I would put in another board.

Investigator -- The board's good

(Pause)

Board is good, the switch was good, and the starter relay was good, so it's got to be a wire problem here, and I've just gotta find it.

8,

trace the wires out

(Traces Wires)

7

-----7,

P6,

ok, 6,

5 that wire's correct.

4,

----ok, 3,

there's 2, there's the 1,

them wires are right.

Now I'm to start tracing them out.

8 goes around and up

8 goes around.

up,

up up

to the ground

Number 7 goes up,

and around to the group,

if it's hooked up right

Number 6

goes around and to the

plus side of the start switch.

Number 5

goes up and around to the field,

Ok. See what we've got there.

5 topside

I believe that'd be right, let's see, number 4

goes over to S-2.

Number 4 solenoid

(Pause)

Ok, number 3

2 goes

S1

S2 goes to there,

Number 1

----inside

Ok, let met check the wiring for the switch out.

(Pause)

Investigator -- Keep talking.

Ok, I'm still looking, trying to find the

problem here for this start problem,

it's getting me stumped.

looking, but I can't find nothing.

Let's see, that's there

Alright

See if I've power into this board

(Test Measurement -- Voltage - PC Board Leads)

I'm checking leads in the board, I just can't nothing anywhere.

And I should have power here,

check my fuse

And let me check, got good ground there, but I have no power coming into the board,

so I've got to have bad connection

or something here.

If you get power coming into the board,

and apparently nothing coming out.

Now, do I have another fuse in this board anywhere.

Still can't get no power through this board.

Unless I shorted it out

(Pause)

Now let me pull that board.

Check the connections underneath.

Investigator -- Before you do that, you put a new problem in here. You put the pin connector on upside down.
Ok, I'll find out here.

(Pause)

(P2 Wire Came Loose)

These pin connectors only go in one way, and

I'll see,

uh I guess that ain't going to work that way either

Ok, I still got my power there and out,

Now I've got my original problem.

Well, let me see what we got here,

hit the switch

(Soft clicks)

Did I,

I'm sure I replaced this switch, but maybe I didn't

replace the start-stop switch,

the solenoid.

Investigator -- Is the solenoid bad?

Ah, that's it,

I think I said I'd replace that first of all, but I'm not sure

Investigator -- No, the only thing you replaced was the switch.

Oh ok, well then I'd start replace the start-stop

Investigator -- And, the board, you would have replaced.

But before that I would have replaced the start-stop solenoid,but

Investigator -- But that's good.

That's good too.

Investigator -- You jumped that.

Ok, well that should have been the first thing I replaced when I jumped it.

Ah,

myself I'm getting stumped then. I've got a couple of wires that's gotta be backwards here, but

trying to find them.

See what we got

(Soft clicks)

Ok, and this one going here down,

would be number 5

(Soft clicks)

Let's see what lead that is.

Number 2 lead

(Test Measurement -- Voltage - P2 Wire)

Ok, let me check the ohmeter out, ok, it says we got power there.

Doesn't say we got power there

Let me check the lead off this way.

And we still can't get power there, so I'd say we got a bad wire or a bad connection here.

We pull the switch and try a continuity test on the wire.

(Test Measurement -- Continuity - P2 Wire)

And, we hook my leads up here.

To that one, and

to this one.

And we don't have no power going through, so we got to have a bad wire here

STOP -- 4:37 TOTAL TIME TO SOLUTION = 22 MINUTES

NOV 4 -- WIRE PROBLEM
START 2:18

(Tries to start - only clicks heard)

Well it's not getting, it's not starting over,

so first thing I'd do is check the battery connections.

Investigator -- Battery's good.

Ok, this is where I'd probably start thinking real hard.

The next thing I'd look at 'd be the starter, see if there's a loose wire on it or anything,

or a bad ground.

(Pause)

And the grounds seem ok and so does the connection,

from there to there.

And I think I'd do, since we've already got it over and got this meter I'd check and see if the starter's ground through the case.

I kind of don't think that's it though, because usually you can, if it's grounded like that you'll smell

Investigator -- What are you gonna smell?

You going to smell the windings, because if it's grounded see it's burning off that insulation and you can just take a whiff around through there and,

(Test -- Meter - Continuity)

see it shouldn't be doing that right there.

You got continuity
between, this here supposed to be insulated,

and you got continuity between there,

so right now, I'd take that starter apart and find out why.

That'd be where I'd go, I'd take this thing right here off.

Investigator -- Starter's good

Starter's good. Now it's going to be more thinking.

Well, now I guess I'm going to have to look at the book.

(Manual -- BGEL Section)

Investigator -- What you're looking for?

I don't know, just looking.

I'd go in here see if I could find something in the troubleshoot. Maybe they got another answer for me.

Cause right there's about when I've exhausted eh

That's not the one I need

(Pause)

Trying to find something that's got a starter related to it.

(Pause)

Investigator -- Talk aloud.

I's trying to find something related to, with a

hesitating and lugging,

not actually doing anything.

I can't find a damn thing in here that tells me what I want to know.

Well, I guess now I'm going to have to go and check what kind of voltage goes into that, maybe it's got low voltage, 'cause that'll make it do the same.

(Test Measurement -- Continuity)

Why do you have continuity here? If that starter's good? Because it's supposed to be insulated through the windings and out.

I'm going to take your word.

Investigator -- Starter is good.

(Pause)

(Test Measurement -- Voltage)

Well we're not getting the proper voltage, near as I can tell.

Just check the fuse it's there, no reason

(Check Fuse)

Well, then, I don't know that much about it but I think I'd take this panel off right here and see if I could find out why that it ain't getting the voltage by going backwards on it.

(Open Control Box)

I think something must be going to ground because,

because that starter case shouldn't have any power on it,

no continuity.

(Pause)

I think I'd check for loose wires first thing.

I'd check the connection up here on the solenoid,

all the way around.

Those seem to be alright.

So I'd check this wire right here and see if we got any voltage on that to connect those relays.

(Test Measurement -- Voltage)

Ok, we're not getting any voltage to that,

so we got to back up some more.

And since all these wires ain't color coded that's a problem.

Kl

So I'm going to go this control panel, see if it can tell me anything in the book.

(Manual -- BGEL)

(Pause)

Checking one more time to see if I can find what I wanted to know first.

(Pause)

It all looks Greek to me.

I'm trying to find something I can reference from where I know what's what.

And I know that schematic's not going to help me, so I'm going to have to look at the pictures somewheres.

(Pause)

Investigator -- Keep talking.

Trying to find something to reference these wires, so I can see the,
see where this wire goes when it comes in.

And that's no help

P1-5 was the number, I think

Kl-S,

Kl

I'm not learning anything.

At all

Investigator -- What are you looking for now?

(Visual Check on PC Board)

Trying to find ah,

something that will tell where this wire goes, from here where does it go up in here, and what does it do.

And I don't know

I don't see anything burnt

I'm going to take this apart, because when you run out of knowledge, you start searching with blind faith.

(Removes PC Board)

Something's stopping the voltage down there.

And I can either work back or go ahead of it and come back on it

(Pause)

Investigator -- What do you expect to find?

Well, I'm looking for something that may be burned, or a

bad connection or whatever.

(Pause)

It looks like there's something been hot right there,

so I'll try to find out what a CR3 is.

(Pause)

CR3

(Schematic - CR3?)

And it looks like Greek.

Start-stop (whispered)

None of the numbers match

Now's when I start feeling real dumb.

It doesn't tell me what a CR3 is.

If I knew what that was, maybe I could determine whether or not that was the problem.

CR2

So I'll try again.

(Pause)

(Whispers, can't understand words here)

I can find everything but that

Investigator -- Ok, what's the next step?

Next step is call somebody,

call the

supplier and find out what that is.

Investigator -- Ok, the CR3 is good.

CR3 is good.

Well, while I had him on the phone, I'd ask him what these other components in here, was there something else that would make that not do, make that not start.

Since I don't know any more about it I'd look to see if I could find where the, where it was coming in and see if there's any voltage on this at all.

Which I think I should have probably done that to begin with.

Which it probably picks up power right off the battery,

on this leg right there

(Inaudible, because of noise from another motor)

Investigator -- What do you get?

(Test Measurement -- Voltage)

We get voltage in. We got the 12 volts there.

So I go over here, try to find out which one's the third one down and where does it go from there.

(Manual)

Which is no help

Ok, now I found something that says where they go to what.

And the P, I guess that's 6, it must be.

P6 goes to K1-B+.

Investigator -- Keep talking.

And I can't find it.

K1-B+,

So I'll look again and see if I can find where that was.

And I can't.

(Pause)

Energizes the K1 start solenoid to close

the K1 contacts.

And now what is the K1 contacts?

I'm getting closer to something, but I don't know what it is.

Contacts

(Pause)

And I don't see anything that looks like a set of contacts.

Anywhere

(Pause)

Well, I'll search some more.

(Pause)

Start solenoid.

Which I think I'm going bass-ackwards

Energizes the K1 solenoid to close the K1 contacts.

I think they're talking about the solenoid there,

so I better start at the beginning.

(Pause)

Run, stop switch from the start position connects battery ground B, to K4 start relay.

Ok.

It's got backed up.

I was going bass-ackwards, I think

So I need to go to this K4 start relay.

So apparently we do have it into the switch, or it wouldn't be buzzing like that.

So I need to look at this K4 start relay.

(Looks At K4)

I can't tell any more about it than

the man in the moon.

But, let's see where it goes from there, maybe I can bypass it.

(Pause)

Investigator -- Keep talking.

I'm trying to find out where it goes once it leaves the start run and goes to the K4 relay, what it does,

what actually the K4 relay does, 'cause if I can put ground to that relay, maybe it'll start, and if does, then maybe I've found the problem.

This schematic to me is worth as much as a

tits on boar hog,

because I can't read it.

So why do I feel lost?

(Whispers, inaudible)

Ok, the K4 start relay goes to

(Pause)

Getting more lost all the time

Investigator -- What do you think's the problem, right now?

Well, the right now at this point, the only thing I can think is maybe this relay's shorting out, either that or it's,

not shorting out but it's open.

Investigator -- Ok, if it were bad, what would you do?

If it were bad, uh, I, well, the main thing

I'd call the distributor again and find out if this K4 was bad, either do I replace it, or replace the board or what, I don't know which.

Investigator -- Let's say we replaced the board and it still had this problem.

Then I'd probably throw up my hands

and go home.

But I'd look for another solution, I really wouldn't give up.

Don't usually give up that easy.

I know there's something dammit that I'm missing.

Right now I've got to figure, is there any systems on this, since I don't know a whole lot about it, I've got to figure is there any systems on here that'll shut that down,

because I can't really see any physical evidence and I don't have the knowledge to test all the components.

And the only thing I can think of would be the oil pressure switch, I think it's got one of those that'll shut it down if we

(The Lop is Good)

That is good,

so I'll try to figure out if there's something else that'll shut the system down, because it may be something easy I'm just overlooking.

(Pause)

(Manual)

I'm gonna to read the list of stuff here I've got, to find out if maybe there's something else in there that's stopping me from running.

Start, run stop switch, start, run and stop,

Heh heh, has a bad ring to it,

start, run and stop.

Think I left my fuse out

(Clicks)

I think ah, probably I'll check and see if there's any voltage,

or enough voltage coming to this switch.

(Clicks)

(Test Measurement -- Voltage - S1)

There's not enough voltage coming to it.

And it's all working off of the, the board that I just didn't understand before

(Whispers)

(Test Measurement -- Voltage to Board)

So I'll check and see if it's getting over there from here.

Ok, it's going in, it's going from, we're getting it from the board, and

we're not picking it up from any of the legs.

It's not there, it's not there, it's not here.

And that says here that that's the start, it's got star, start ground and stop,

so if I had some kind of jumper, I'd probably try to jump that with 12 volts, and see if that would make it work.

And I was checking it the wrong-ass way.

(Clicks)

We're getting closer,

I think we should have from this middle leg over to the other post, so now's when I need the jumper.

And I don't think that makes a bit of difference

(Clicks)

Now I've got to try to figure out whether I'm jumping the right ones or not.

(Clicks)

And I'm not,

or I am and it's not making any difference.

Now's when I start crying, buddy

I've got to wonder if anybody else solved this problem.

Ok, that's the P3,

and that's going here,

we're getting it there

I'm getting voltage there to the switch,

so that's the end leg I believe.

(Clicks)

And when I hit the deal, I get a drop on the center leg,

and no,
nothing on the other leg.

So having plenty of money, I think I'd replace this switch.

Investigator -- The switch is good.

I think you told me that once, didn't you

Investigator -- No, that was something else.

Ok, it's going in, and it picks up from there and it goes back out. And now to try out where in the hell out is.

Investigator -- What you're looking for?

I'm trying to see if, if where, it's got a two connection deal here, like it picks up from there and goes somewhere else

and I think that's kind of a blind alley.

Hmm. this is another tough part, 'cause now I've got to come up with another theory.

So if it's not coming out of there, I've got a voltage drop, that's the part I don't understand.

There's a voltage drop here,

and why in the hell don't uh, you got 12 volts there, and we'll go to the center one,

we should hit the switch and there's no voltage.

I'm hardheaded so

(Pause)

(Test Measurement -- Continuity - S1)

It must be a bad sign when you don't take no for an answer,

Ok you're right , the switch is good.

Well, I don't, I very seldom take people's word for anything, 'cause usually they lie to you

Ijust mean that's you know, from experience tells me not to.

So now I've got to go back to what would shut this thing down, what is there in here that would make this not work right.

And I don't know the answer to that,

so I better start coming up with an answer.

If the power comes in on that to control the circuit board,

then it's got to go somewhere else.

(Pause)

(Schematic)

So I'm back to the schematic, trying to understand Greek again.

K3,

fuel solenoid,

that can't be it.

And where does it go from there,
K4

to the start relay.

I think I've done been through K4.

Investigator -- The board is good, K4 is on the board.

Ok. Well, that was kind of cheating, because I'd a been on that board forever I think.

Run relay.

Doesn't make a lot of sense,

if uh

K3 run relay,

breaker points, power rectifier,

fuse, starter motor, generator, I can't find a damn thing that's going to help me out.

K1,

start solenoid.

Right now we'd go back to

assessing the first part of the problem.

Trying to find out

(Test Measurement -- Voltage - K1)

No volts, let's see,

see make sure we're getting voltage out,

'cause I, be honest with you here, I've forgotten what I'd already learned. Obsession with that board. And it's not getting 12 out.

And I'm going to check it again to make sure something

to that solenoid.

(Clicks)

And we're not getting anything to it.

So the likelihood of the solenoid being bad is remote,

in my opinion.

But I think I'd jump it just to make sure, I'd jump from point to point

(Jumps K1)

That kind of confirms it,

that does what everything's supposed to do, so it's not the solenoid, and it's not from here and it's not the starter.

I've eliminated those things.

So we're back to trying to figure out what the hell's shutting this

board down.

And I don't know what that would be.

But something has to shut this board down, if the switch is good.

And it's got to shut it off between.

It doesn't make sense, but something may be wrong between this and starter, the start switch,

and I don't know what the hell that would be.

Unless maybe we got a loose wire.

(Test Measurement -- Continuity Between Board and Switch)

(Pause)

So I guess what I'd do now would be try to check the continuity between these wires,

to see if there's a wire that's messed or a connection that's messed up.

(Long pause)

Investigator -- What are you getting?

I'm getting good readings on all of them so far,

which is discouraging.

Investigator -- Well, we've taken just about enough time on this.

STOP -- 3:03 TOTAL TIME TO NO SOLUTION = 45 MINUTES

NOV 5 -- WIRE PROBLEM
START 3:32

Ok, I'm going to try to start it.

(Clicks)

Yeah, won't turn over it looks like, I'm going to check the batteries.

Investigator -- Ok, battery is good.

Battery's good, Ok.

Let me look for a loose cable.

(Pause)

Fuse looks good,

could take a continuity check on it,

I'm sure that's what I should have done.

(Clicks)

Checking the wire that goes to the starter,

for tightness.

Loose wires anywhere that I can see.

Cannot.

(Pause)

I'm still looking for loose wires.

(Clicks)

Investigator -- Keep talking.

(Looks Into Generator)

Ok.

I'm looking to see if anything would start to turn while I'm,
while I'm trying to start it.

The only way that I could think, I think that it may have a bad starter on it, but I do not know how to check the electrical on that starter, do you check it just like we did? We talked about it from ground? How many volts does it take to start it? I don't know that

Investigator -- OK, let me tell you, the starter's good.

Starter is good? Ok.

We'll go back.

I'm going to open this electrical system up and just look again and see what if I can see on this unit, I'm going to look and see if I can see what's wrong with it here.

(Long pause)

(Removes Control Cover)

I'm looking, I'm taking the cover off of this so I can see inside of it.

As of right now I don't see any loose boards, I don't see the board that, if the board is burnt on the back and it is not, it doesn't look bad, of course that doesn't always tell you that it's bad.

Ok, if I've got current going into, the the battery is good, if I got current going into the solenoid and I don't have it coming out of the solenoid to start the, the only thing I could think it would be would be the solenoid.

Investigator -- Is there a way to check that?

I really don't know. I would say that it was the solenoid, being as the battery is good, it has got power, and ah, of course I didn't check the starter, but you told me that it's good

Investigator -- Starter is good.

So I would assume that it was the solenoid, which you of course you can't go assuming a lot of things.

Investigator -- Why don't you just put a jumper across the solenoid?

Ok.

Well, it turned over.

I touched it from side to side, and the engine started it, I mean the generator started to turn over, but

it wasn't going very fast, of course you've got a small wire trying to turn over a big engine.

Investigator -- That solenoid is Ok.

Ok, the only other thing

(Clicks)

The only thing, the other thing that's wired up to the solenoid is your, either the off and on switch, which I do not believe, your rocker switch

(Clicks)

Let's see how that be tied into that.

Ok, Yeah, I'm guessing that the board, even though that the board doesn't show, of course like I say you can't go to that, that the board

(Clicks)

to me,

let me do a little more checking here, the board doesn't, see where the board goes to and how it comes out of it.

(Pause)

Ok, as I say again, I'm guessing and I'm saying it is the board or the rocker switch.

And I don't know how to check the board, to be honest with you I don't know how to check the switch. Let me check the fuse for continuity again. I mean I never have checked it but I looked at it, the fuse doesn't look like to me that it is bad.

Investigator -- It is good.

The fuse is good. Ok.

Ok, the board has,

the board does not look like it's bad, but the wires going into it from the solenoid, and back out to the ground, I'm saying that the board is bad,

like I say,

that, that would be my guess as far as I know right now.

Investigator -- Ok, are you having power into the board?

Well, like I say, I don't know how to check for that.

I don't want to mess up a board, because I do know that you can short one of these out and smoke them in just about two seconds, so

I don't know exactly where to start, let me see here, this has to be power into the board which would be a guess, I've got power into that part of the solenoid, so this is your power going into the board, and uh, let me see here,

And then it's got a ground coming out of this, the same board

going
like I say, to the ground side.

And from I understand, all Emeralds are

on ground, in other words, that's their last stopping from what little bit I know about the electricity part.

So I like I, I do not know how to check the board from this point on.

Investigator -- Ok. What if I told you the board was good?

Then I would say that it's the switch.

Investigator -- Why would you say the switch?

Well that's the next thing in the circuit.

According to what I could see.

Investigator -- When you press the switch, do you have any power?

No, it does not.

(Clicks)

Doesn't feel like to me that the switch is bad, but I always thought that the circuit board would be bad because the switch does feel like it's good, and it does make some effort to start, and, you know, acts like that it is getting power but the power's not coming through to the solenoid.

You telling me that, and that's starters trying to turn over, whenever that I jumped across the solenoid, so there's nothing, I don't think there's anything internally wrong with the engine, uh,

in, you know, in the electrical part of it,

and it still puts me back to the board or to the switch.

And I do not know what this big switch is up there for unless it's to turn on the power to the main, uh

Investigator -- Which one?

This one back here

Investigator -- Circuit breaker, that's all it is.

Ok. So, like I say, it's on, but that's pretty well to end of my,

as it stands right now, pretty well to end of my rope.

Investigator -- Ok

I don't know where to go from here.

STOP -- 3:42 TOTAL TIME TO NO SOLUTION = 10 MINUTES

Appendix H
System Understanding Interview Data

EXP 1 -- SYSTEM UNDERSTANDING

Investigator -- Let me have you identify a few parts. What is this?

That's your start-stop and run switch, 1 and 2 for stopping, 1 and 3 for starting.

Investigator -- How does this work inside?

It's a rocker switch, uh, you got the middle contact, it's a normally, it's common to both sides. Ok, when you hit the rocker switch, the contacts opposite those you're hitting will be making contact. If you're looking at this switch, this rocker switch, and you hit the right side, the center one and the left will be making contact. If you go to the stop side an easy way to remember it is the center one and the right one will be making contact if you're on the left side of the switch. You got an insulated terminal over here, we had shorting problems, it was put against here, so when it slips into the housing to keep it from shorting out. Because we had a problem where that was unplugged at one time, and we ran into problems, so that was done that way.

Investigator -- This?

That's your starter solenoid. You have B+ applied to the one side, you got a energizing coil on it, and the other side goes to the starter. When you hit the start switch, it comes through the circuit board, applies B+ to the solenoid, causing it to pull in and crank.

Investigator -- What happens if this is faulty?

Well, there's several different symptoms you can have, ah, we've had some as soon as you plug in the battery cable it cranks. Other times you can put it in you'll just hear, you'll hear the solenoid pull but you'll have no voltage to the starter, so a simple way is you come over here, you take and measure, of course you got B+ over here, you come over here to your energizing terminal and your starter solenoid, and you measure, if you got voltage here it's fine, then you go over to the other major B+ terminal and put a meter over here. Now if it chatters to that, and you don't get any 12 volts over there, then you know that you have a problem with this. Now, providing you have 12 volts over here you can assume that you got a good ground and everything. If you got a poor ground or that, it can cause problems especially on the start circuit where you have a higher current drop, so what we do over here is if your fuel pump's pumping and everything, and your solenoid gets a good solid pull and good clicking sound, come up to your energizing circuit on your starter solenoid, and you check and you got 12 volts over there, then you go back to the GenSet make sure you got a good ground. You also make sure you got a good ground strap from there to your mounting tray and from your mounting tray down to your truck chassis, depending on where they hook the battery cables, and now some will hook the negative battery cable right to this tray or that then it's no problem, but if it grounds through the coach, the negative side, then you got to make sure you got a good ground. Using good shakes, make sure there's no rust, no corrosion, keep them good and tight. Winnebago has a problem where you go a deep dish tray, comes awful close here to your fuel pump, if you got inline fuel filter, you got flexible hoses, that's very critical that you keep those hoses and the fuel filter away from that tray, so when it rocks, the unit will rock and cause the hose to flex. Now if you have your fuel filter close to that mounting tray, it'll chafe the hose, cut it through and you got a potential spark problem. Also, this battery cable over here, you got to make sure you got the rubber boot on it, it's a easy for it to short out. The solenoid mounts on kind of a offstanding bracket, it's kind of flexible, depending on the mechanic, if he isn't careful and he wrenches it down with a half inch wrench a little too hard, he can bend that bracket, and without this protective rubber boot on here, it can short out B+ and it can start a fire, especially near gasoline and stuff like that. So, I guess part of the service problem would be to make sure you got a good rubber boot on here, make sure the cable's bent away, and make sure the post is kind of centered in the slot. We got a new one coming out, will be kind of a cutout over here, with a mounting side that'll eliminate that problem, cause they found out it was one of the hazards.

Investigator -- Here?

That's your starter motor, it hooks up to the, there's a ring gear that's pressed on the rotor shaft and that ah, turned the rotor's fit on a taper, on the back of the generator, about 50 pounds, that makes a good tight fit, there's no keyway, uh, when B+ is applied to the starter, it'll rotate the ring gear on the rotor. Now of course we've already assumed that it's been tightened down, so it's tight on the back of the crankshaft, making it like a solid shaft, so when the gear rotates around, also the engine will rotate around. When you assemble this, it's a good practice to take, to keep interference and out of round, take and mount the generator housing first, and then tighten the rotor through stud, that way it keeps everything aligned. You got your front main bearing, your rear main bearing, and you got your generator support bearing, and when you tighten your rotor through stud, it keeps everything on the center line, whereas if you got the rotor hanging here and you tighten this rotor nut first, then you can have a slight angle, it can still line up in a thing. Now you got enough mechanical cranking power here so it'll do it, but it'll take a little bit more to crank the engine over, a little bit more runout, it'll cause a little bit more wear and tear especially on the main bearing, center rear main bearing, two outer ones, it'd be just like a something out of whack, and just kind of a tumbling action. We got one or two generators where that's impossible to do, but we got a centering collar that kind of eliminates that, you got a taper, you got a centered recess over here, so by mounting this stator housing first, the engine generator adapter, and then tighten your rotor through stud, you'll keep out vibration plus you take and you make it for a truer running shaft, from the crankshaft through the rotor shaft and that should reduce like I say cranking power plus vibration which will make better mounts, your bearings will last longer everything, smoother running unit.

Investigator -- How about this?

That's a condenser, goes to the positive side of the ignition coil, you got making and breaking into points, and you got other relays and stuff, it filters out the AC voltage at the coil like when it collapses and everything, keeps it from being induced back into the DC circuit where it'll hurt other components.

Investigator -- How does this operate, physically?

Well, basically in the high peaks it'll charge up, and the low ones it'll feed back into the circuit where it has a leveling effect to keep it almost like pure DC. If you got a spike or like when the coil collapses, part of this will be charged up in the condenser. And then when the coil's conducting in this will feed back into it, kind of get, level it out.

Invrestigator -- When you push that start switch, how do you end up with AC output?

Ok. You have voltages fed, when you first hit the start switch, voltage is fed right from your battery through your circuit board, to close contacts A1K3 through a diode, A1CR2, through a printed circuit board connector plug A1P1-5, it feeds to the positive side of your bridge rectifier which is located in your stator housing, which is CR4. It feeds voltage through there, also where your fuel wire's hooked up and it feeds voltage right straight to the brushes for intial buildup, you don't have any imbedded magnets or anything to start up the residual. This is a good positive voltage fed right into it. The reason is we've had a lot of problems in the past with units, especially along the coastal areas and that where you got moisture in the air, humidity, you got a film buildup on the AC brushes and the residual magnetism isn't enough to originally build up the generator voltage. So by doing this we eliminate a problem. Ok, we start to crank, providing everything else is good, we've got voltage now coming from our circuit board to CR4 and it reads directly to the brushes at this time and we feed voltage through our field windings, and we're putting the 12 volts for reference across the plus and minus of the bridge rectifier CR4. Ok, providing everything is good, the regulating transformer is good, the generator will start to build up voltage. As the generator builds up voltage, around 80 to 90 volts, it's fed to the regulating transformer, T2. You have voltage that's fed back to the rectifier, and this will vary. You go across your one side here and you got variable voltage connections, there's a chart on this diagram over here and whether you want to increase or decrease the voltage. And the way it feeds voltage back, S2 and S1 goes through the transformer by our backup, your bridge rectifier. As your generator builds up more voltage, it feeds AC voltage to this bridge rectifier, it'll take and rectify this AC voltage to DC, feeding it back to the field. Of course, if your voltage goes too high, your regulating transformer will put more resistance in there, effectively AC resistance or impedance, bring the voltage back down. And as you take and you build up less voltage for that, or bring it back up again, more will be felt across this transformer, more AC voltage will fit over to your two AC terminals on your CR4, more AC voltage fed back at your AC terminals and CR4 will mean more voltage rectified and felt across your positive and minus terminals on your bridge rectifier which feeds back to your field winding in your rotor. Of course, more voltage there. You have higher voltage rotating at the same speed that's more induced voltage into your stator stationary winding and it brings the AC voltage back up again.

EXP 2 -- SYSTEM UNDERSTANDING

Investigator -- I want to ask you to identify a few parts and tell me how they work, so this?

Start-stop switch.

Investigator -- How does that physically work inside?

There are, there's a piece of metal that rocks back and forth as the switch works. If you press on on one side, as you press on whichever side I'm not sure which, if this is start or the stop, you're rocking the piece of metal between the center and this

opposite side of where you're pressing on the switch.

Investigator -- If it's a faulty switch, what symptoms do you have?

Probably just not working at all.

Investigator -- And this part?

Start solenoid.

Investigator -- How does that operate?

There is a coil on the inside, an electromagnetic coil. This is the B+ input to that coil, it is internally grounded. When you apply B+ to that terminal the electromagnetic coil pulls in a an armature which hits two contacts and makes continuity between one post and the other post.

Investigator -- And this?

Starter.

Investigator -- How does that operate?

It's an electromagnetic motor, a DC motor, um brushes on the inside, um, when you apply DC um to the post uh it creates magnetic fields on the inside. There's permanent magnets on the uh on the inside of this, you're creating fields on the rotor which causes it to turn.

Investigator -- How does it turn the engine?

There's a little bendix gear up here, as it starts to spin, the bendix gear pushes out and engages with a flywheel which has teeth on it on here, um, as the engine speeds up and gets going faster than this, or as someone releases the start switch or we get start disconnect, the plastic pinion pulls back out.

Investigator -- And what about this?

That's no longer used on this, well. It's radio suppression, it's a capacitor.

Investigator -- How does, how does that work?

How does it work? It's like a miniature battery. Um, it's got two plates on the inside, two different kinds of foil wrapped tightly together, one is a negative one is a positive, um, it tends to take AC and either not pass the AC or clamp it.

As a matter of fact we found that this one actually hurts us. So that one's coming off there.

On the new Emerald Pluses, we found that as the voltage to a, the ignition voltage got to a certain point, that capacitor was starting to break down, and particularly at loaded conditions, so they're going to remove that. That capacitor will now be, on the new board it will be on the board as part of the circuit.

Investigator -- When you press that start switch, how you end up with AC output?

Ok. When you press the start button, you engage the start solenoid which engages the starter and starts the engine cranking. At the same time when you press the starter, um, the the board puts DC to both the coil and to the to the fuel pump, and also to the field flashing on the generator. As the engine starts to gain speed, the generator starts building up voltage, um, there's a relay on the board and a couple of resistors. As the voltage gets up high enough, the relay on the board engages, which is a start disconnect relay.

EXP3 -- SYSTEM UNDERSTANDING

Investigator -- I want you to answer a few questions and identify some parts and explain how they work.

Investigator -- What is this?

That's the start stop switch.

Investigator -- How does that work inside? (Physically.)

It's a single pole double throw switch. Makes a connection between this one and this one to start it and this one and this one to stop it.

Investigator -- What is this black device in here?

Start solenoid.

Investigator -- How does that work?

It's electrical solenoid that pulls in when you energize this terminal. Connects positive to the start solenoid or to the starter motor and makes it crank.

Investigator -- How does the starter work?

DC motor. DC power into it, armature turns as a result of the field.

Investigator -- How does that turn the engine?

Gear on the end engages the ring on the fly wheel. Spins the engine.

Investigator -- And this part?

That's the ignition that's the suppresser. It's a condenser on the positive side of the ignition.

Investigator -- And what's that there for.

That's probably just noise suppression I don't know.

Investigator -- How does a condenser work?

Well it's nothing more than a capacitor. It will ignore any given set voltage but uh an induced voltage or a spike of a high enough magnitude will be will arc across it. And be shunted to ground through the case.

Investigator -- Can you explain to me how when you push the start switch and start this up you end up with AC power?

Well the engine's the prime mover. It spins the armature of the generator. The stater is the armature and it has a rotating field. The revolving field induces voltage into the the ah the armature leads which are in the stater and it comes out through the output leads. It also is controlled by the transformer. Based on the load that is on the output. And you get the voltage out of this receptacle.

Investigator -- What's the field flash?

Field flash is what causes the generator to build up. It's ah takes excitation from the battery and energizes the field to make it build up.

EXP 4 -- SYSTEM UNDERSTANDING

Investigator -- Let me ask you a few questions Just want to make sure you understand the system and what some of the parts are So identify this part.

That is the start stop switch.

Investigator -- How does that work inside.

Well it's ah a spring loaded ah switch return ah return to center ah when activated in a start position these these two contacts the center contact and the contact on the right are connected together in the stop position the center pole and uh the left contact go together.

Investigator -- And this black thing right here?

That's the start solenoid. We apply B+ to the switch terminal here to energize the solenoid for cranking and that takes in closes the set of contacts which apply battery voltage to the starter.

Investigator -- And this?

That is the starter.

Investigator -- How does that work?

Ah battery voltage is fed from the start solenoid to here causing the starter to rotate.

Investigator -- How does it get the engine turning?

It has a gear on the end that engages with the flywheel and causes it to turn.

Investigator -- And what is this?

That is a capacitor. I will make the assumption that this is one of the units that doesn't have the condenser in the point box so that is probably the condenser.

Investigator -- It does have one in the point box.

It does. OK. That's just an additional suppression condenser then.

Investigator -- To suppress what?

Suppress RFI.

Investigator -- Just give me a general picture of how this whole thing works. When you press the start switch describe what's happening to get AC output.

OK. When you press this the start switch ah you're energizing the start solenoid causes the engine to turn over. You're also energizing ah through A1-K3 down through the bridge rectifier which goes into the field which starts the excitation process. And once the engine is up and running uh the generator will self excite by the AC inputs to the bridge rectifier. The A1-K3 contacts open and it sustains itself after that.

EXP 5 -- SYSTEM UNDERSTANDING

Investigator -- I want you to identify a few parts and I want you to tell me what parts do and how they work. What is this part here?

Start stop switch.

Investigator -- How does that work inside?

It's just a rocker switch. When you push it to the start position that makes contact from the center terminal to the terminal number 3 on the switch which energizes the start solenoid.

Investigator -- What else is energized then when you push the start switch?

The fuel pump. And the ignition coil.

Investigator -- And the black part here?

Is the start solenoid.

Investigator -- How does that work?

B+ is applied to the coil of the solenoid. The other side of the coil is grounded. When you put B+ on the positive side it engages the start solenoid.

Investigator -- And this?

This is a starter. And that is gets it's B+ from the start solenoid when the start solenoid is engaged it pulls the coil in contacts are made and it applies B+ to the starter.

Investigator -- When you apply B+ here how does it turn the engine over?

The starter the starter motor's the engine I guess is what you'd it's a DC motor starter is what it amounts to.

Investigator -- What about this?

That's a capacitor. It's used I believe it's used for radio suppression. It has really not much to do with ah actual ignition with the unit to the unit.

Investigator -- How does a capacitor work?

Well as it ah voltage builds up to a certain point and then it it well gets to a peak it'll collapse again and keeps going up and collapses and filters it filters the ah voltage I guess spikes you might want to say.

Investigator -- When you push the start switch to start the engine how do you end up with AC output? Just a brief description of the total total system.

Well you're getting your field is energized as you're cranking the engine starts, the rotor turns, the field turns, it's going through the starter windings and through a magnetic field and produces electricity.

NOV 1 -- SYSTEM UNDERSTANDING

Investigator -- I'll just ask you to identify a few parts. I'll ask you how the part operates and what the part does. What is this part?

It is my start stop switch.

Investigator -- And how does this start stop switch work?

OK a start switch ah what it does is ah it makes a connection ah to complete a circuit uh to tell the engine to go ahead and turn over. It completes a circuit.

Investigator -- Looking at this or looking at the wiring schematic can you tell me what what happens on this unit then when you activate the start switch?

Ah well when I push the the start switch um related to my schematic um I want to find the, see what number they call the start switch.

(Reading Schematic)

S1. Ok. Ok I have my start switch here to make S1. I push to start which Ok OK I'm reading my ah my battery positives has to go through the control assembly to A1 which is K4. Which I don't see a listing for K4 not knowing what it is. Part of my uh control assembly. Ah going to W1, my jumper wire, A1-P3. I don't know.

Investigator -- What happens if the start switch is defective?

If the start switch is defective ah S1 does not make the connection it can't make that the circuit which would not allow it to start.

Investigator -- What is what is this part back here?

The start solenoid.

Investigator -- How does a start solenoid work?

Ah not sh-, I'm not ah ah positive but ah my start solenoid tells my ah ah ah gives my uh starter the OK to start ah one test I maybe could've taken that I didn't take was ah jumping the over to a ground which I didn't do.

Investigator -- Can you identify this part?

That's a starter.

Investigator -- How does that physically work?

Ah starter is what ah ah turns ah the crank t-

Investigator -- How does it turn it?

With the gears inside the starter.

Investigator -- How does a gear turn?

Ah with the power which is from the battery.

Investigator -- Ok electrical power.

Electrical power.

Investigator -- And if the starter doesn't work?

Ah it doesn't uh the starter does not work um your engine does not start.

Investigator -- And one more, what is this?

Ah condenser to uh that goes to the ignition coil um not knowing the emerald one but on the on the NH it doesn't play a big part as far as it starting stopping I I believe that you could disconnect the condenser and it wouldn't have any bearing on its starting or stopping.

Investigator -- Do you know how a condenser works?

Ah no. Ha ha ha.

NOV 2 -- SYSTEM UNDERSTANDING

Investigator -- I want you to identify some parts. So let's start with this.

Alright, that's ss starts, and start 'n kill switch.

Investigator -- How does that physically operate?

It's got two open contacts, it flips either way to close each contact, to either start or shut the engine down

Investigator -- When you push it to start, what happens beyond it?

Ok, if you push the starter switch, it should go through your K1 circuit on your PC board, go through your board to your starter solenoid, which activates your starter, you should get. It also should send fire, it should activate to send fire to the coil so that it can run the engine.

Investigator -- And if that is a faulty switch?

If this, a faulty switch, it won't start

Investigator -- Ok, any other things will happen?

Uh, yeah, you might not be able to shut it back down once you do, if you do get it started it might not shut back

Investigator -- What is this, black

That's a solenoid, starting solenoid

Investigator -- How does physically operate?

That is, some of them are ground activated, some of them are hot activated, this one is a hot activated solenoid, positive activated solenoid.

Investigator -- So when it's activated, what happens?

When it's, when you throw power to your S side of the solenoid, it should activate the battery that, it should make the full contact between the one side of the solenoid to the other for your battery and your starter.

Investigator -- Ok, and if that's faulty?

If that's faulty, then your unit won't start.

Investigator -- How about this?

That's the starter.

Investigator -- How does operate?

That activates on like a, you, when hot comes to it, it conducts itself, or I'm not sure, I'm not real familiar with how the starter works, but, on the armature, and it cause a magnetic field which turns it to kick in, to turn the engine over to start it.

Investigator -- How does it turn the engine over?

By the ring gear

Investigator -- And if that's not working?

If that's not working, the engine won't start.

Investigator -- How about this?

Alright, that's the capacitor, or uh, or a condenser, whatever you want to call it, stores energy that's left over when you shut the unit down.

Investigator -- Ok, how does it store energy?

Eh, I'm not real sure, but I know it will knock you down if you grab hold of it (laughter)

Investigator -- Why is that on there?

That is on there, from what my presumption, I haven't ready anything, you know, anybody ever tell me anything about it or anything, but when you shut it down, it'll, whatever's left over in the coil should go over into this.

NOV 3 -- SYSTEM UNDERSTANDING

Investigator -- Let me just ask you a few questions on a couple of parts, and I'll ask you to identify the part, and I'll ask you to tell me how it physically operates. So, we'll start with this part.

Well that's your remote start, start-stop switch

Investigator -- Ok, remote?

Well, your, ok , your start-stop switch for the generator

Investigator -- How does that physically operate?

Well, On this generator set I'm not sure. I know on the other generator set when you stop it, it in turn, you've got current, it goes through the relays in here into your solenoid. On this particular model you hear, turn it off, it sends current into the board, the board interprets you're going start it, it sends it out to your start-stop solenoid, or I should say your starter solenoid, which in turns open it up, which sends power to your starter, in turn turns it over. At the same time the circuit's opening up and sending power to your points and to your fuel pump.

Investigator -- What if we open that up what would it, how does it look inside?

It's just like a little rocker switch, I believe, inside.

Investigator -- Which does what?

That's got like little contact points, you set it to the off position-----the contact points, it grounds your power out. It more or less shuts your 12 volt power going off to your points and your fuel pump at the same time on the Onan power plant. It's like a gregit, negative ground stop system is what it is.

Investigator -- If you I've got a faulty start switch then, what can happen?

It could start up on you at any time, or it could shut off it could quit on you or it might not do nothing at all.

Investigator -- What's this?

That is your starter relay.

Investigator -- And how does that physically work?

Your starter relay you've on this particular model, you've got positive cable in, you've got a positive cable out, which is no power to it until power is applied to the third post, the small post in the middle, the power applied to that what it does, it opens up, creating a flow of electricity through the start-stop switch to your starter, to start the unit up. You let off on the switch, power ceases to go the middle point, which cuts off the power through, which cuts off the power to your starter.

Investigator -- If that's faulty?

If that's faulty, you won't have no start on the generator.

Investigator -- What about this?

This is your starter back here, that's just 12 volt starter, grounds through the generator unit itself.

Investigator -- When you apply 12 volts to that what happens?

Well, when you apply 12 volts to this, it turns over I believe on this one clockwise, which in turn is connected to your flywheel ring gear, which turns over your engine and starts the generator plant if everything else is functional.

Investigator -- Ok, a faulty starter?

A faulty starter you'd be able to check with test leads, uh you'd want to make sure when you start you press your start-stop switch, that you'd have 12 volts going into your starter. If you don't have 12 volts going in, you could have another problem. If you got 12 volts going in, and it still doesn't turn over, you've got a chance of either faulty starter or a frozen up generator plant.

Investigator -- What about this thing here?

This is your condenser for your points on your electrical part for your ignition. What it does, it cuts your power down, to I believe it's 6 ohms, if I'm not mistaken, 6 or 8 ohms, otherwise you'd have a chance of burning out your coil.

Investigator -- Now is that for the ignition points?

This, now, you've got another---one in here for your ignition points, which protects the ignition point. This one here just protects your coil.

Investigator -- How does this work?

That's just uh, what does is it pulls resistance, it's like, well actually it's a type of resistor, I believe, that uh, you get your 12 volts coming in, it picks up your 12 volts what it does is------maybe this one here is for your static, I'm not sure.

NOV 4 -- SYSTEM UNDERSTANDING

Investigator -- I just want you to identify a few parts and tell me how they operate. What's this?

That's a start switch.

Investigator -- How does that physically operate inside?

Well, there's power in, then when you switch this, it's supposed to transfer power over here.

Investigator -- How does it transfer power?

Ah, mechanically, there'll be a, either a little flipper or some balls or deal in there, and that'll transfer the power.

Investigator -- What happens if that's defective?

Well, what happens if that's defective, ah, you lose the continuity between your points.

Investigator -- Which causes what on your unit?

Then, this won't work, it won't work because from here it should go somehow over to the solenoid, and that'll energize this, which is they call their relay, and that way you'll get power from battery to starter

Investigator -- How does this solenoid work inside?

Uh, the way that he explained it over the, up there was that you got the two points and there's a spring that's uh, uh holding it down and then when you put power to this, it makes the magnetic field pull and that will connect the two points.

Investigator -- Whats are some symptoms of a bad solenoid?

Uh, kind of like what we're doing right now, power not going through that.

Investigator -- What is this unit?

That's a starter

Investigator -- How does that operate?

Well, what happens with that is, you get power uh this particular one best I can tell is, you got power coming in here and it's already activated by the solenoid, and there's a set of contacts in here and that makes the magnetic field here and it rotates the rotates the armator and the armator as it rotates either it's got a mechanical, but no it don't, it's got a centrifugal force starter drive that comes out and engages into the flywheel.

Investigator -- What is this part?

Condenser?

Investigator -- Yes. How does this condenser work?

Uh, I don't know on this, but a condenser usually takes the excess charge from the coil.

Investigator -- Why would that be on there?

To take the excess charge from the coil so that it wouldn't burn up the points.

Investigator -- Can you tell me one more thing? When you push this start switch, what happens in here to end up with AC power?
When you push the start switch? Well as ah, when the motor starts running then it turns the, on this one it was a field rotating, so it rotate the field, ah rotating field on a, on the armature, which is stationary, and the two magnetic forces crossing each other makes the electricity.

NOV 5 -- SYSTEM UNDERSTANDING

Investigator -- I just want you to identify a few parts and tell me how they work. So what is this?

Ok, that is a rocker, the way I've got it pictured, is a rocker switch.

Investigator -- How's that work inside?

Ok, it looks, it should be two points set on a rocker switch that when you pushed, it should have one set of contacts that start, should be on the other side, should have a set of points that's the way that I've got it picture, when you push it, it uh kills it, breaks the breaks the circuit uh, you can't run it to ground because this runs on ground, so I'm saying that it breaks the circuit.

Investigator -- And when this is pressed, then what is activated?

When you press that, ok, when you press that, goes to the solenoid, you should have hot wire that goes to the solenoid which would be 12 volt, which would activate a solenoid, snap it down into a set of points, uh, let the uh electricity run through on the set of contacts, go up to the other pole, of course, and go over to the generator which is um activated which start, turns the engine over.
Investigator -- What happens if that switch or solenoid is bad?

Well, seems like to me that if the solenoid was bad and we went through it with a meter, that we had power every place we've supposed to been, if probably wouldn't even snap. I'm just saying , you know.

Investigator -- What would happen to the whole engine here?

It wouldn't do anything.

Investigator -- What's this?

Starter.

Investigator -- How's that work?

A starter has a bendix on, ok it's got a rotor in it and ah when it gets the 12 volt electricity or whatever it's running on, uh, the armature goes around, shoves the bendix into the flywheel and turns the engine over.

Investigator -- And if that's faulty?

If it's faulty nothing.

Investigator -- What's this?

That's a capacitor.

Investigator -- How does that work?

Ok, I really don't, know much about capacitors. The way I understand it, it stores power until it is needed for the start, the way I understand it.

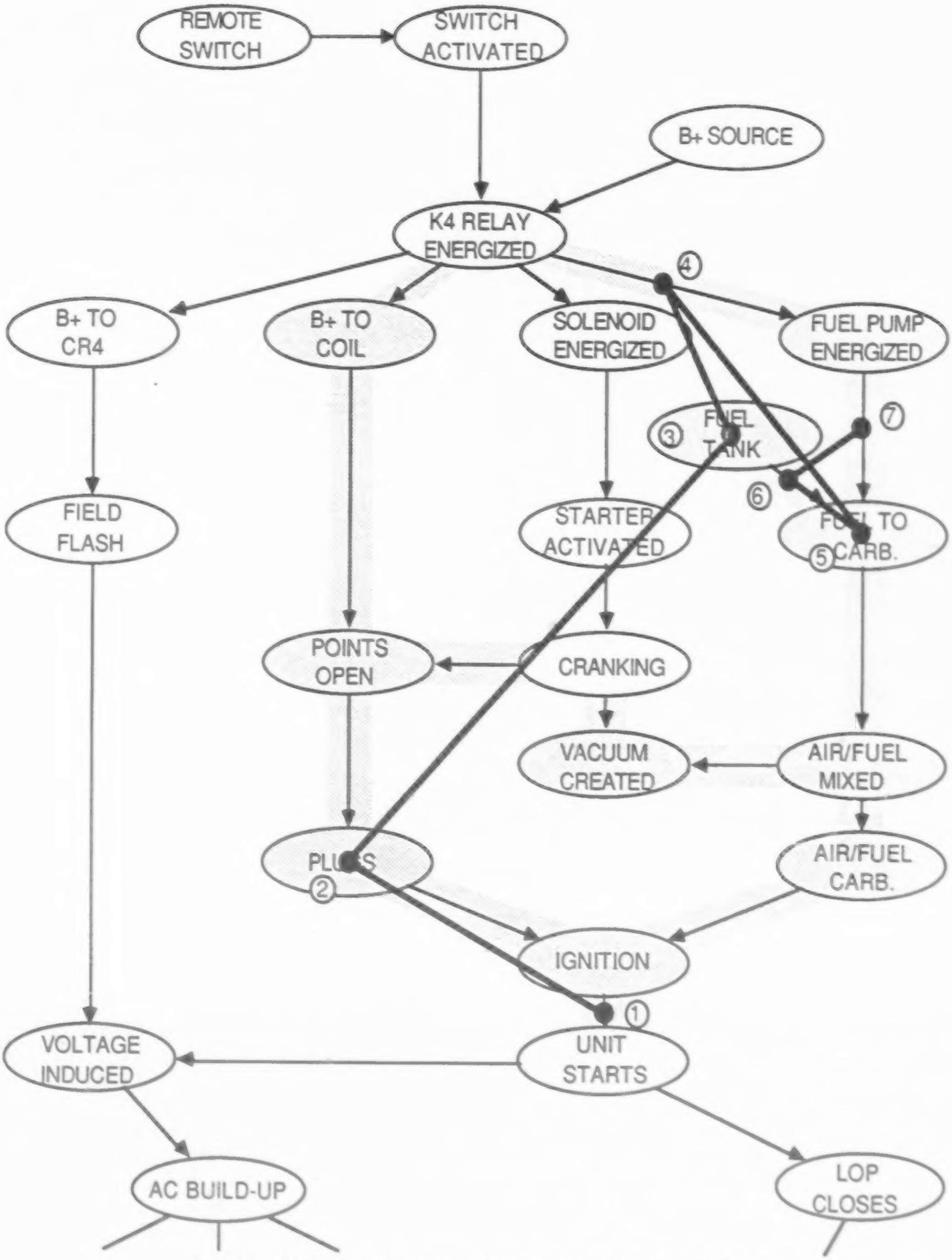
Investigator -- Can you tell me in broad terms, when you press that start switch and start the engine, how do you end up with AC power out?

Ok, when the engine starts, it turns a, of course I don't know, I'm thinking on this particular one it turns the rotor, I'm sorry, this one turns a, well, I can't think straight, anyway it turns in the inside with a magnet field, uh, the stronger that the motor turns, the more the magnet field comes and generates more electricity to bring it out through the brushes and everything and the slip rings and brings it through the exterior power into your motor home or whatever you got it plugged up to.

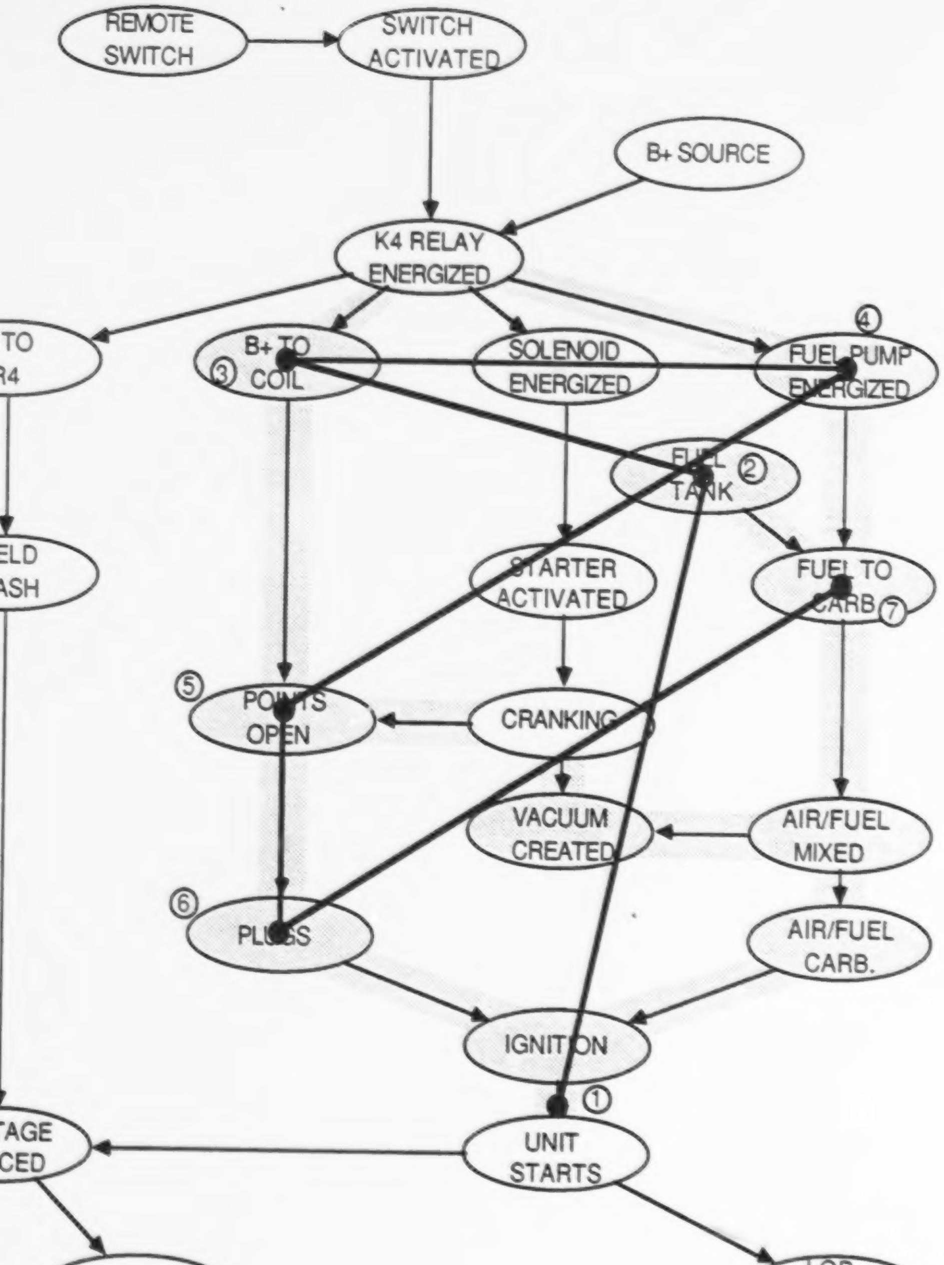
Investigator -- How does the turning create the electric power?

By magnetic, by magnetic field of some sort, whichever way that you're going.

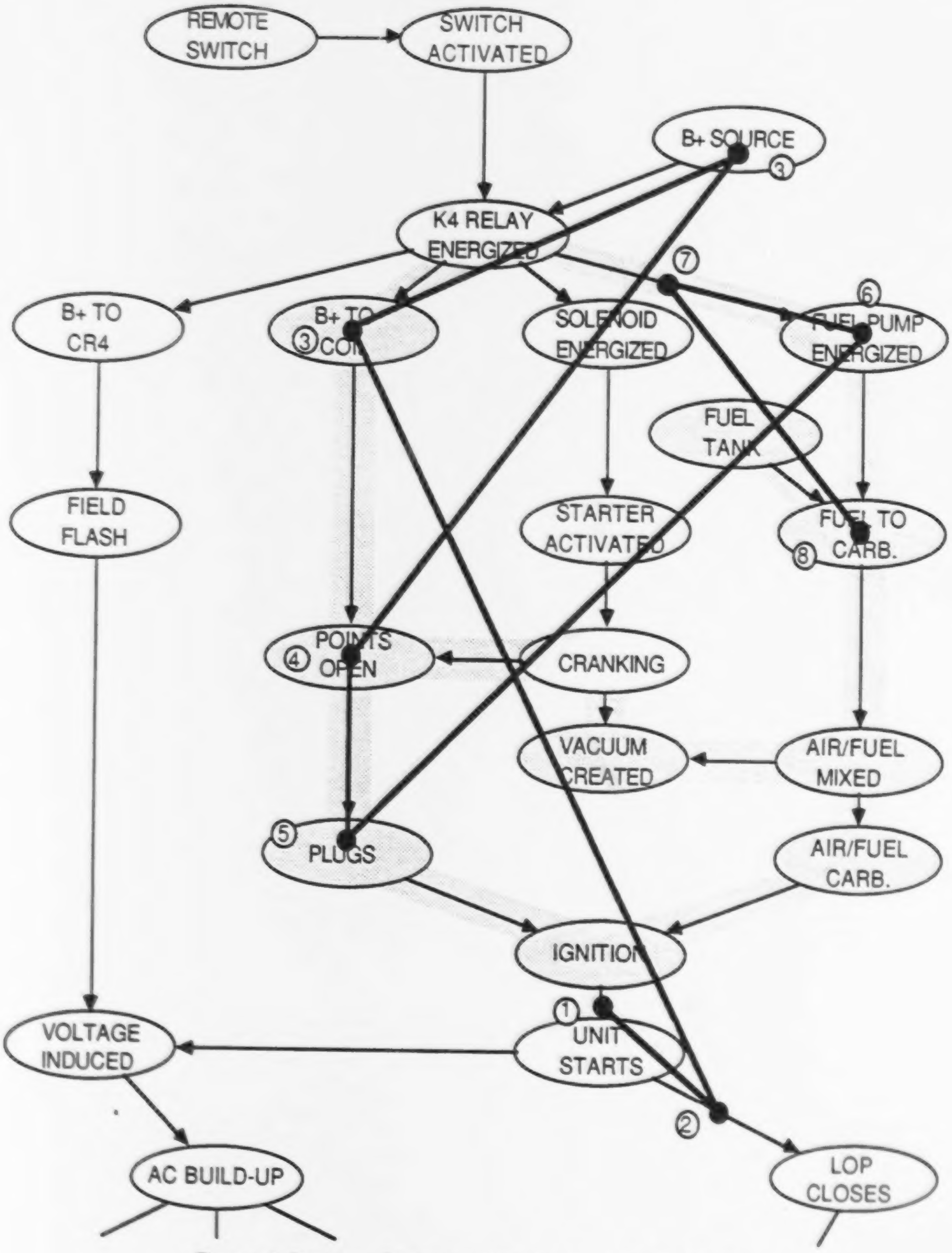
Appendix I
Problem Behavior Maps


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES
①
②
③
④
⑤
⑥
⑦

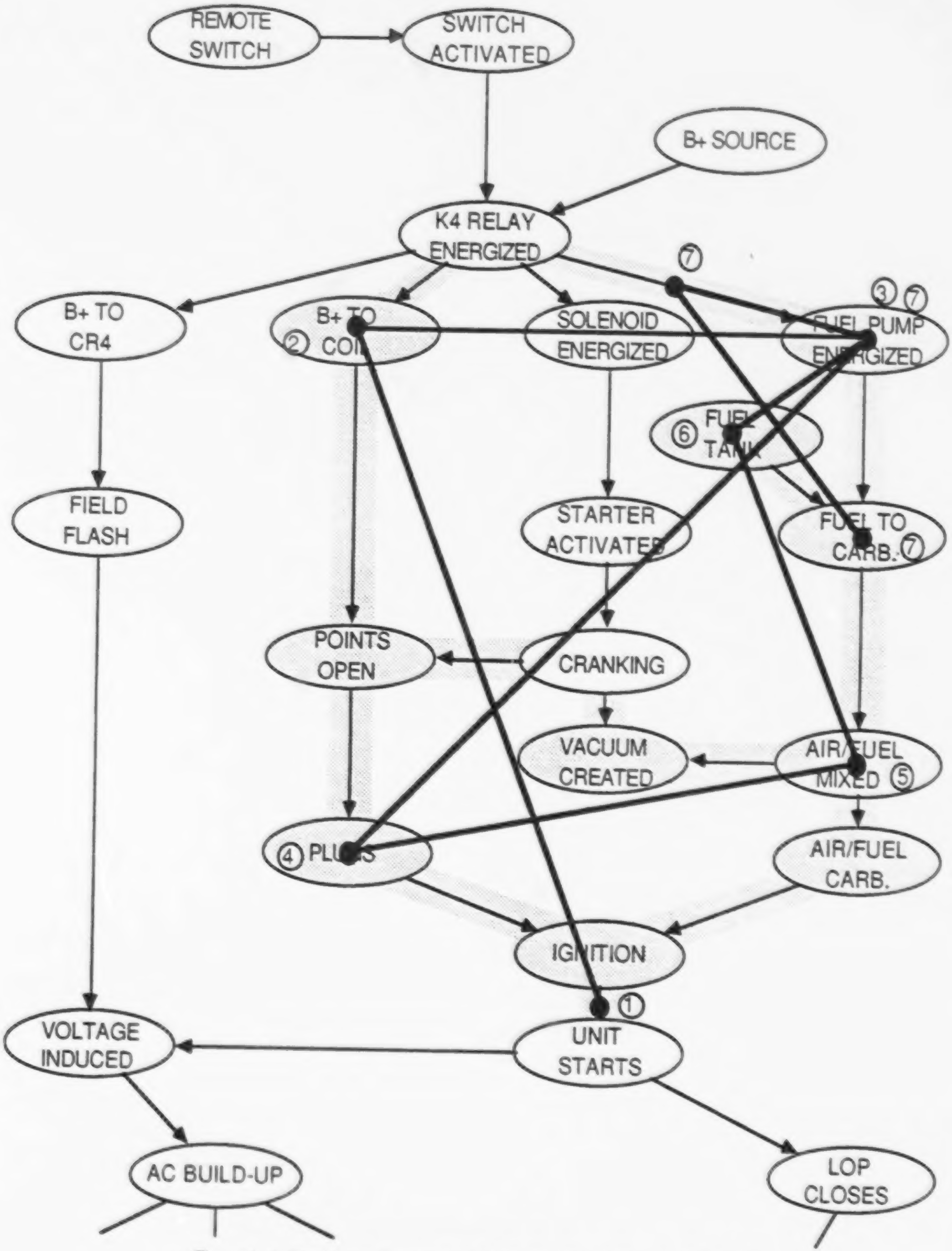
Expert 1 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
③
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
④
FUEL TANK
②
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB
⑦
⑤
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
⑥
PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

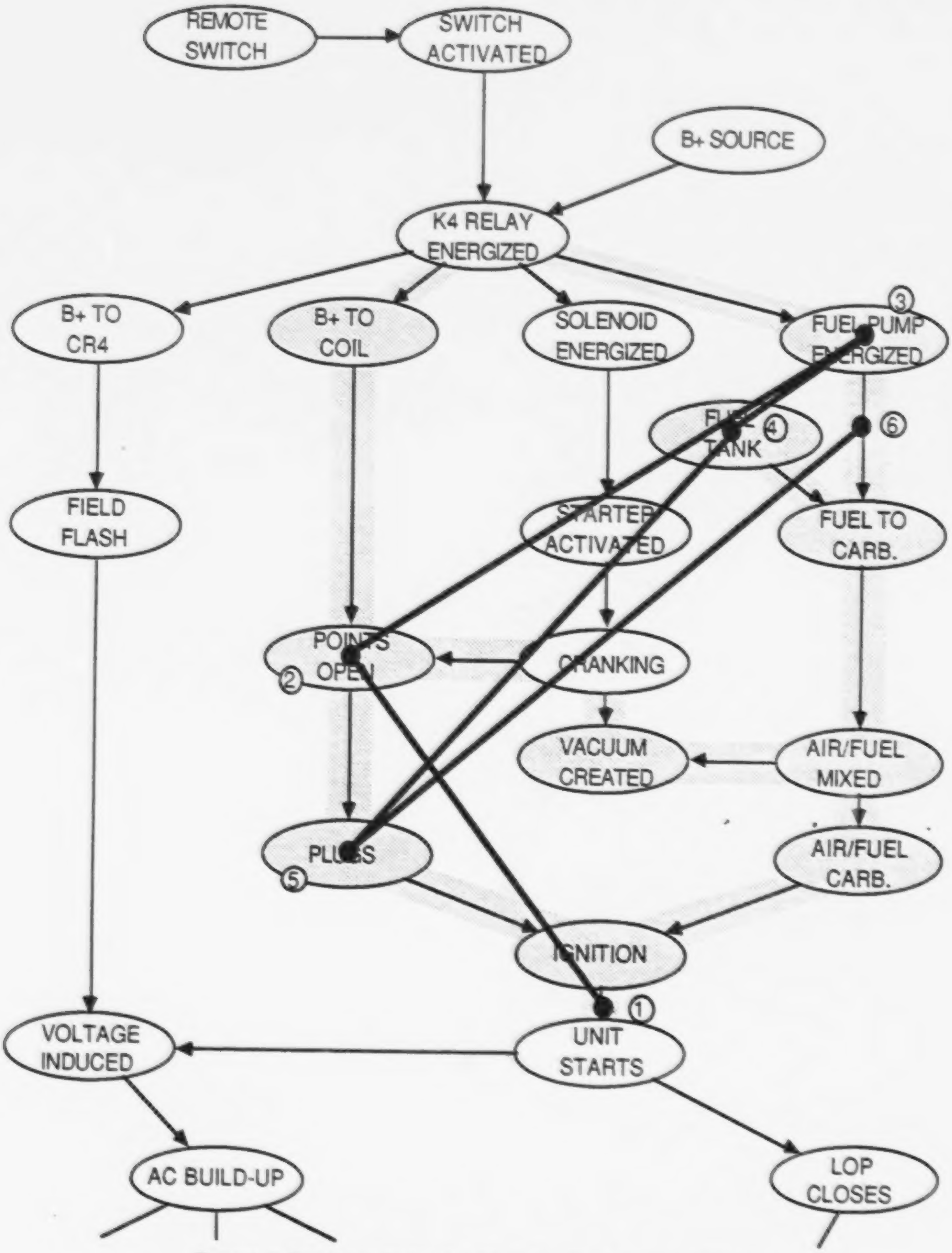
Expert 2 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
③
K4 RELAY ENERGIZED
⑦
B+ TO CR4
B+ TO COIL
③
SOLENOID ENERGIZED
⑥
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
⑧
④
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
⑤
PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
②
AC BUILD-UP
LOP CLOSES

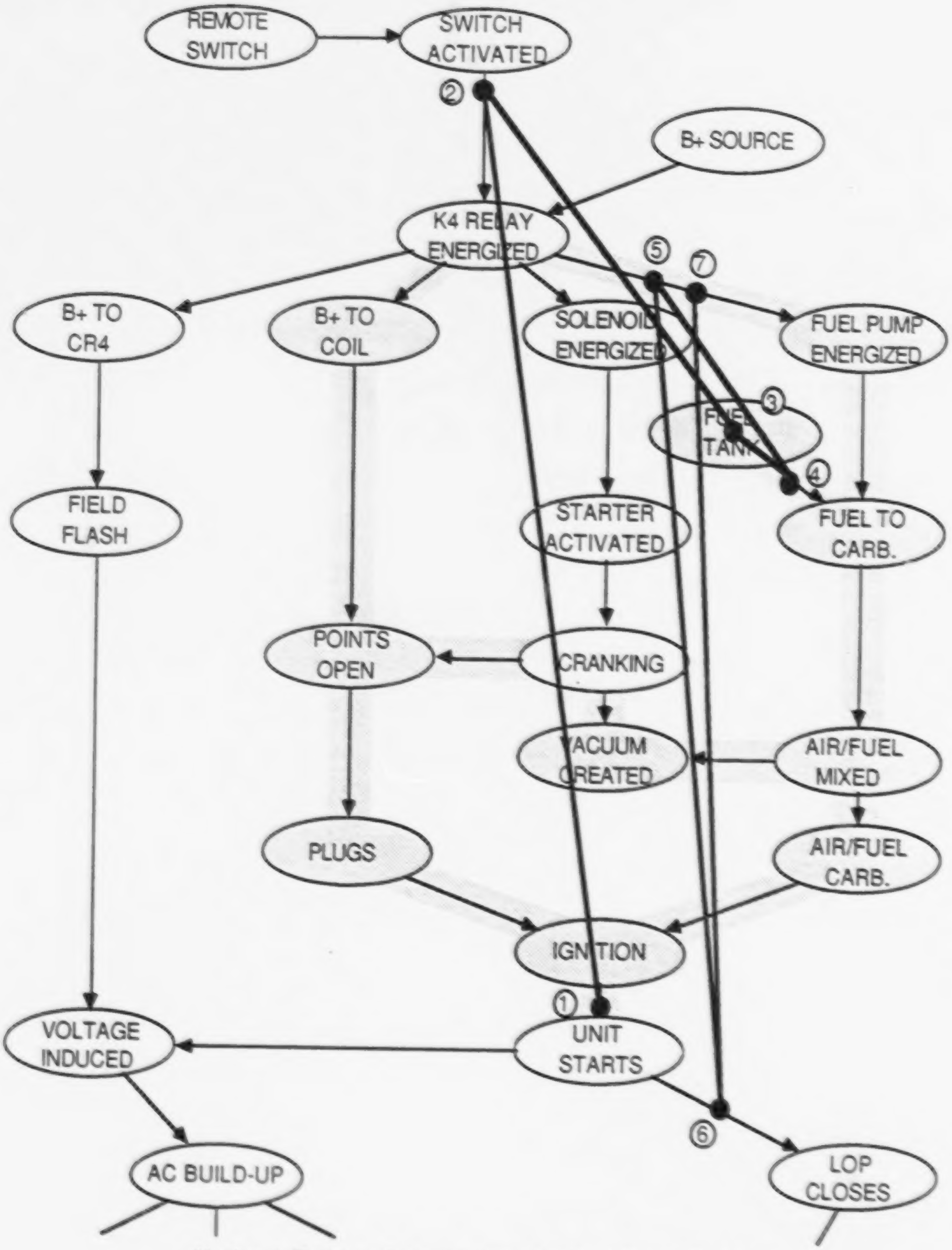
Expert 3 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
⑦
B+ TO CR4
B+ TO COIL
②
SOLENOID ENERGIZED
③ ⑦
FUEL PUMP ENERGIZED
⑥
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
⑦
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
⑤
④
PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

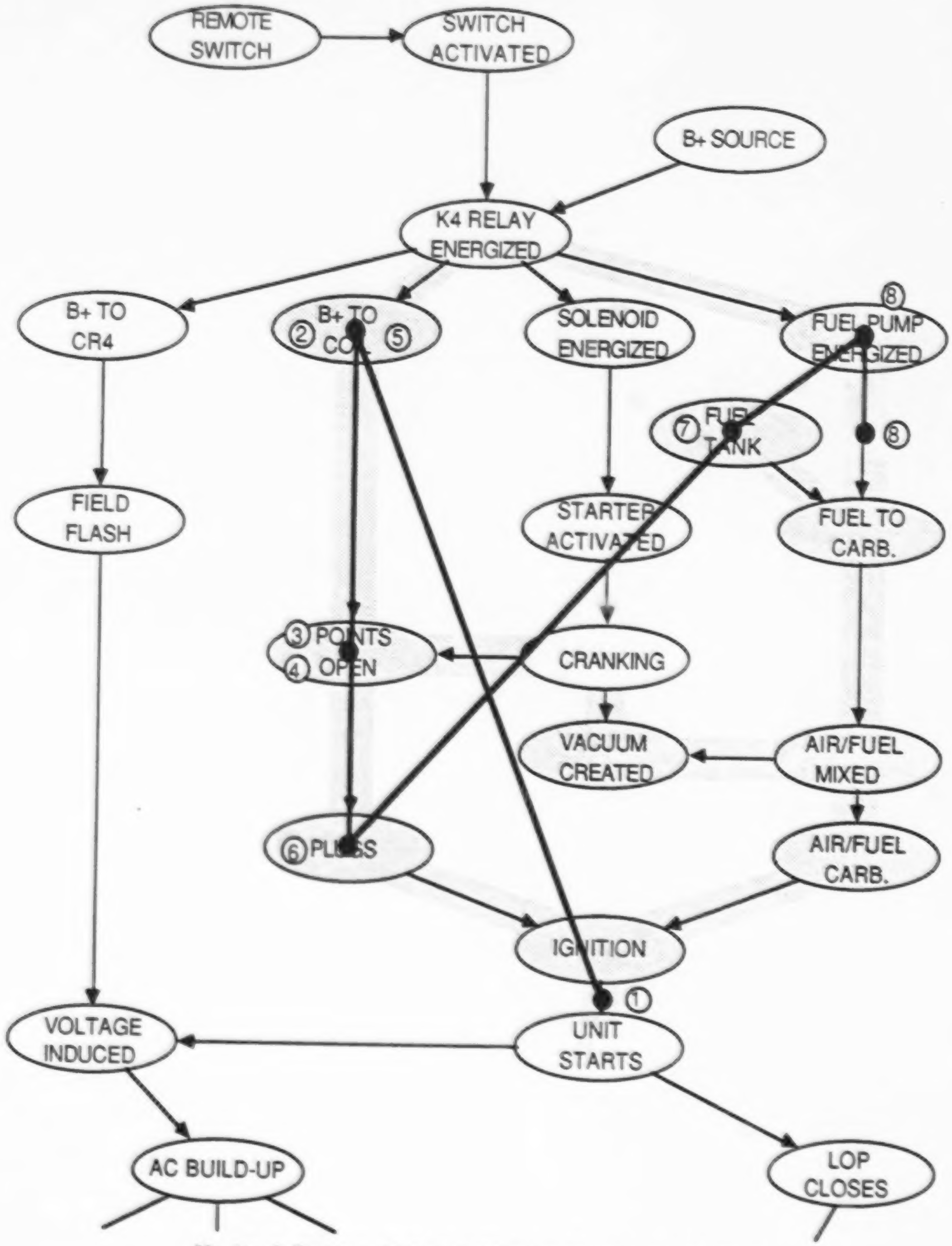
Expert 4 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
③
FUEL PUMP ENERGIZED
FUEL TANK
④
⑥
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
②
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
⑤
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

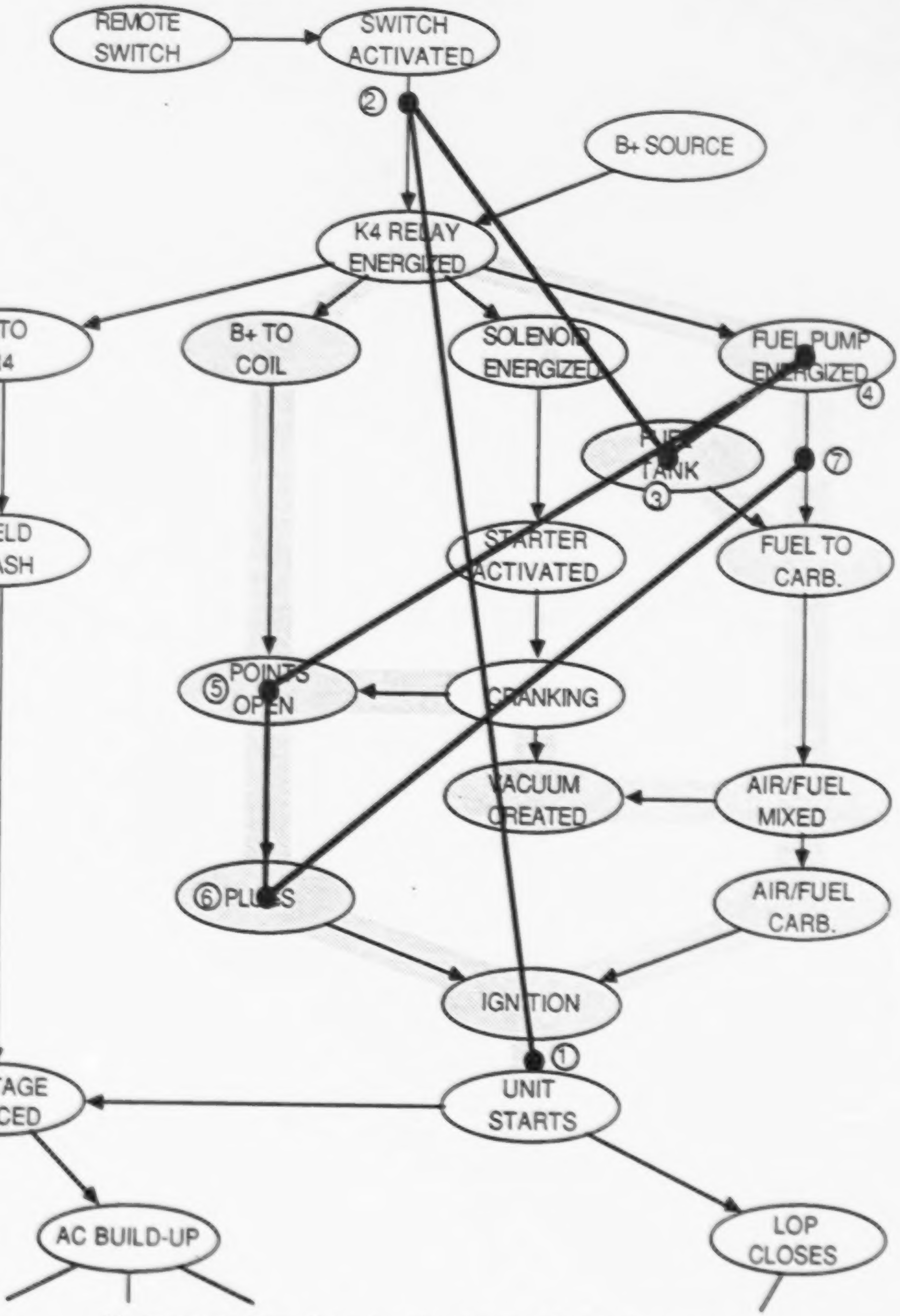
Expert 5 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
②
B+ SOURCE
K4 RELAY ENERGIZED
⑤
⑦
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
③
FUEL TANK
④
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
⑥
AC BUILD-UP
LOP CLOSES

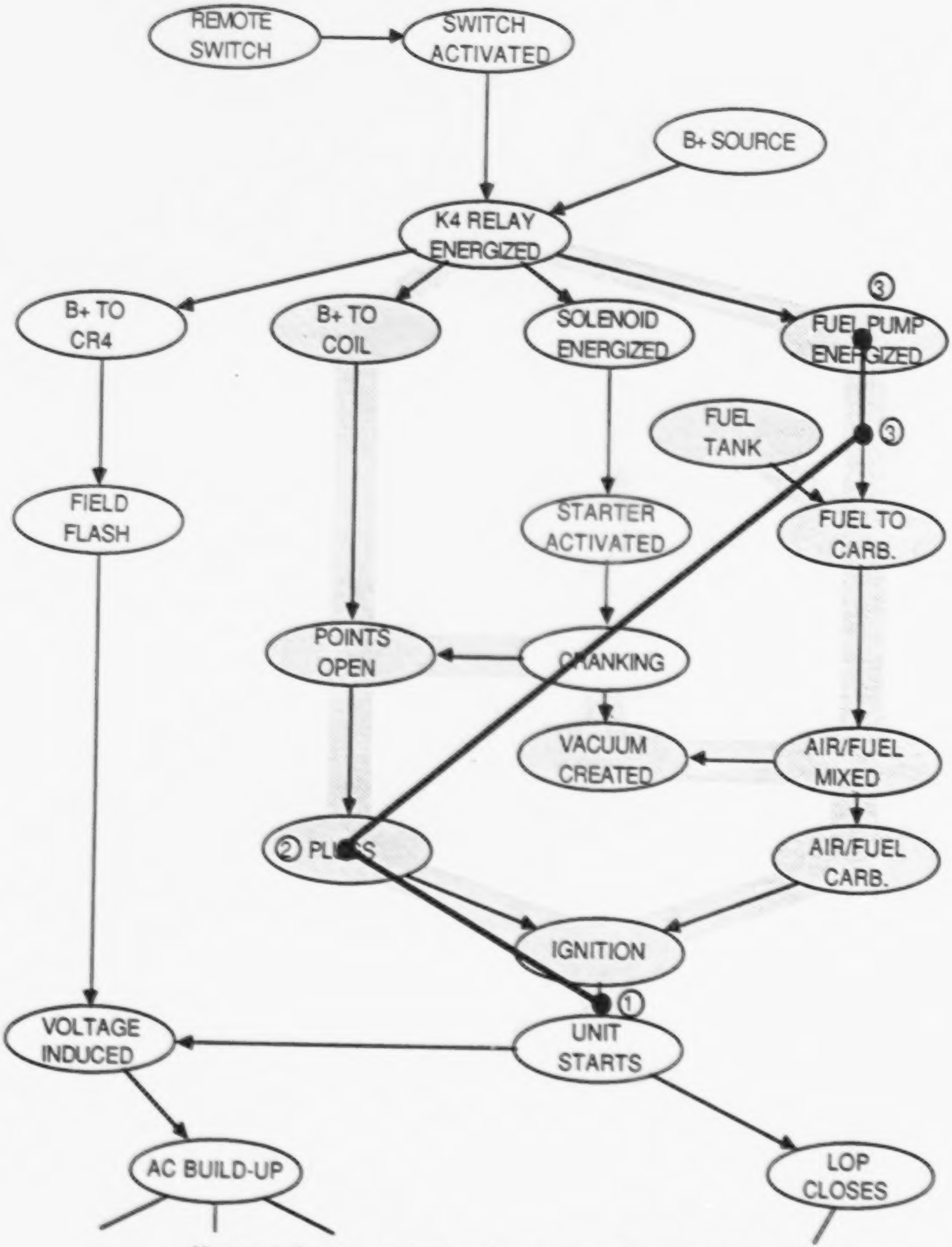
Novice 1 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
②
⑤
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
⑧
FUEL TANK
⑦
⑧
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
③
④
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
⑥
PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

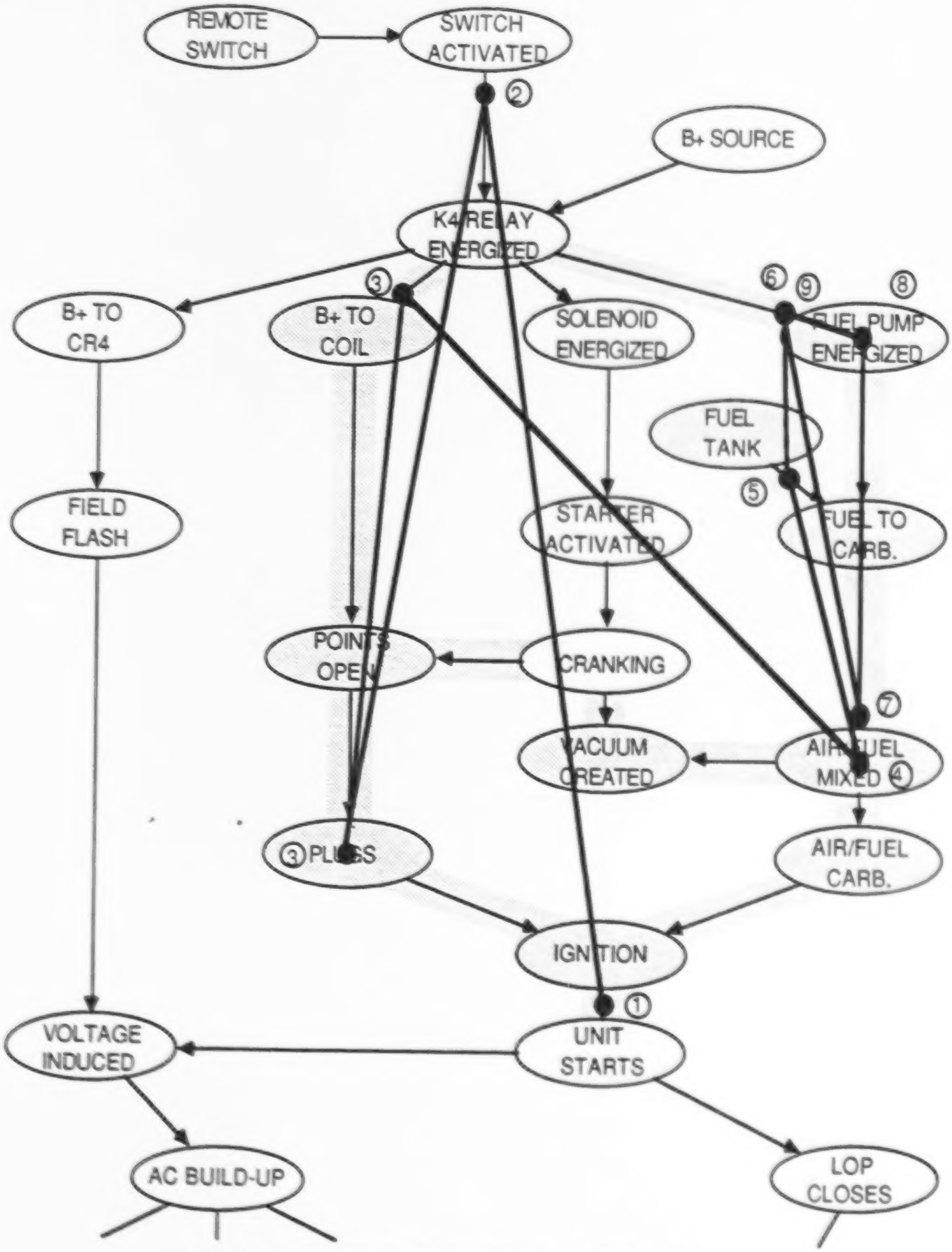
Novice 2 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
②
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
④
FUEL TANK
③
⑦
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
⑤ POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
⑥ PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

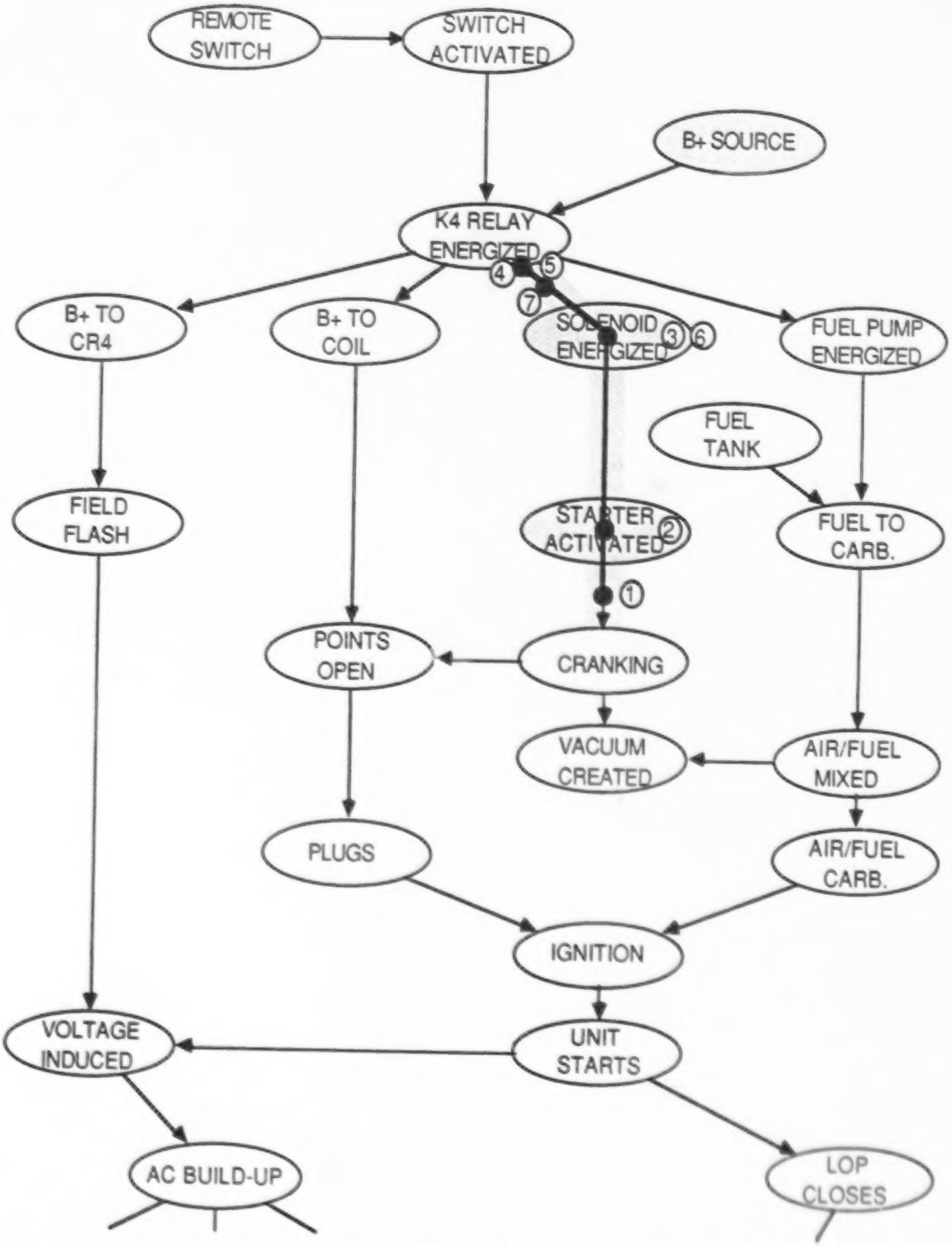
Novice 3 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
③
FUEL PUMP ENERGIZED
FUEL TANK
③
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
② PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

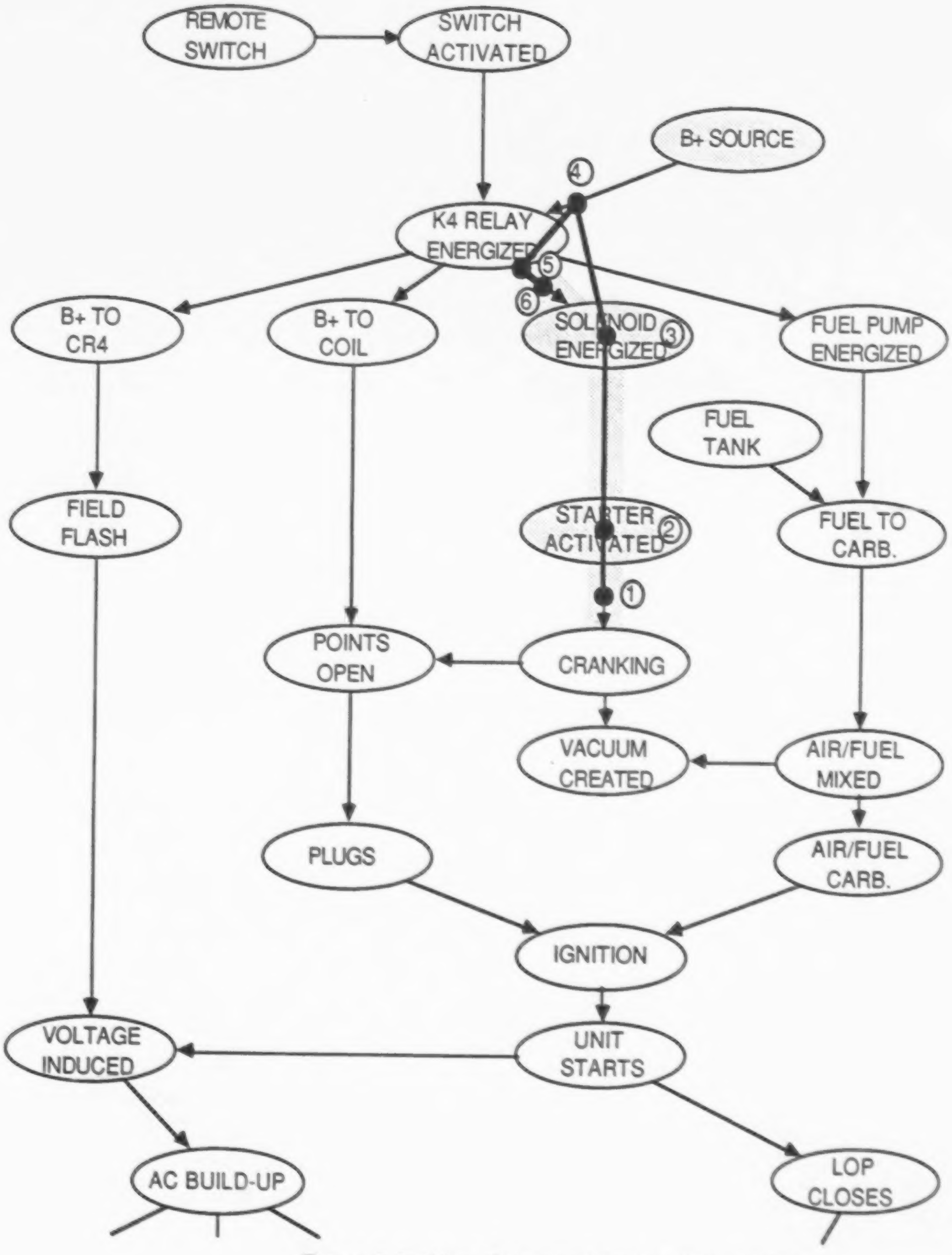
Novice 4 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
②
B+ SOURCE
K4 RELAY ENERGIZED
③
⑥
⑨
⑧
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
⑤
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
⑦
VACUUM CREATED
AIR/FUEL MIXED ④
③ PLUGS
AIR/FUEL CARB.
IGNITION
①
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

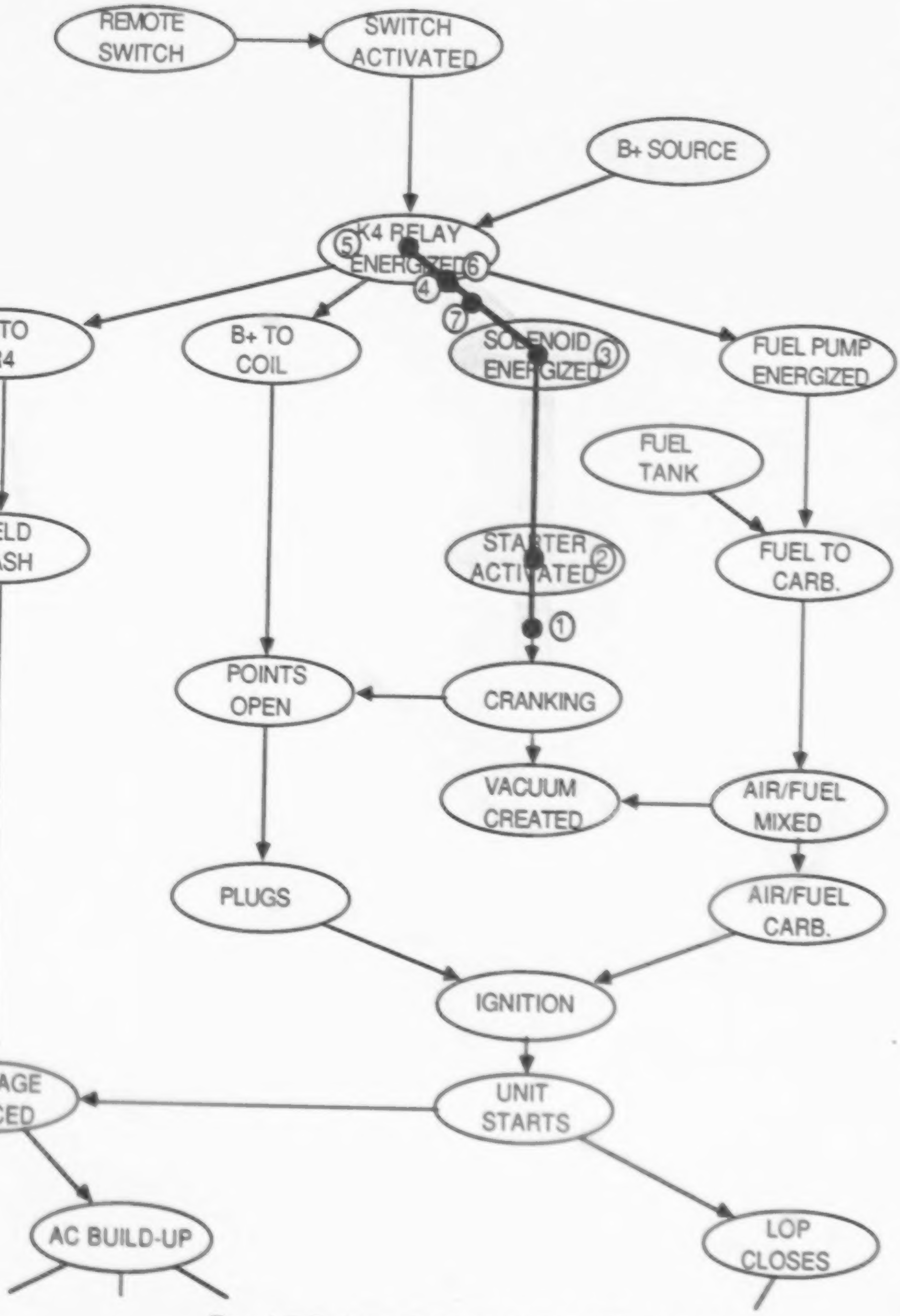
Novice 5 Problem Behavior Map for Fuel Pump Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES
①
②
③
④
⑤
⑥
⑦

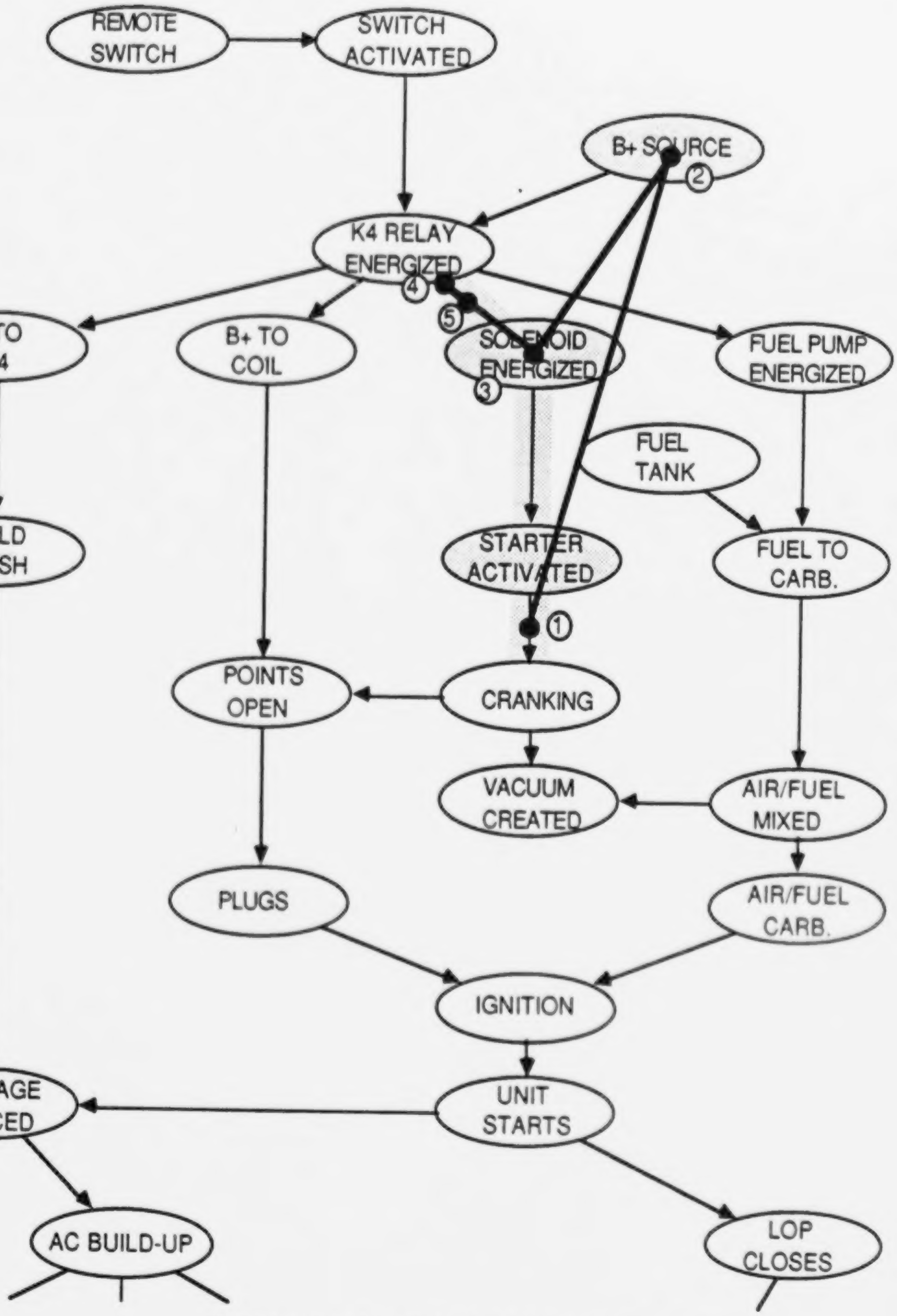
Expert 1 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
④
K4 RELAY ENERGIZED
⑤
⑥
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
③
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
②
FUEL TO CARB.
①
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

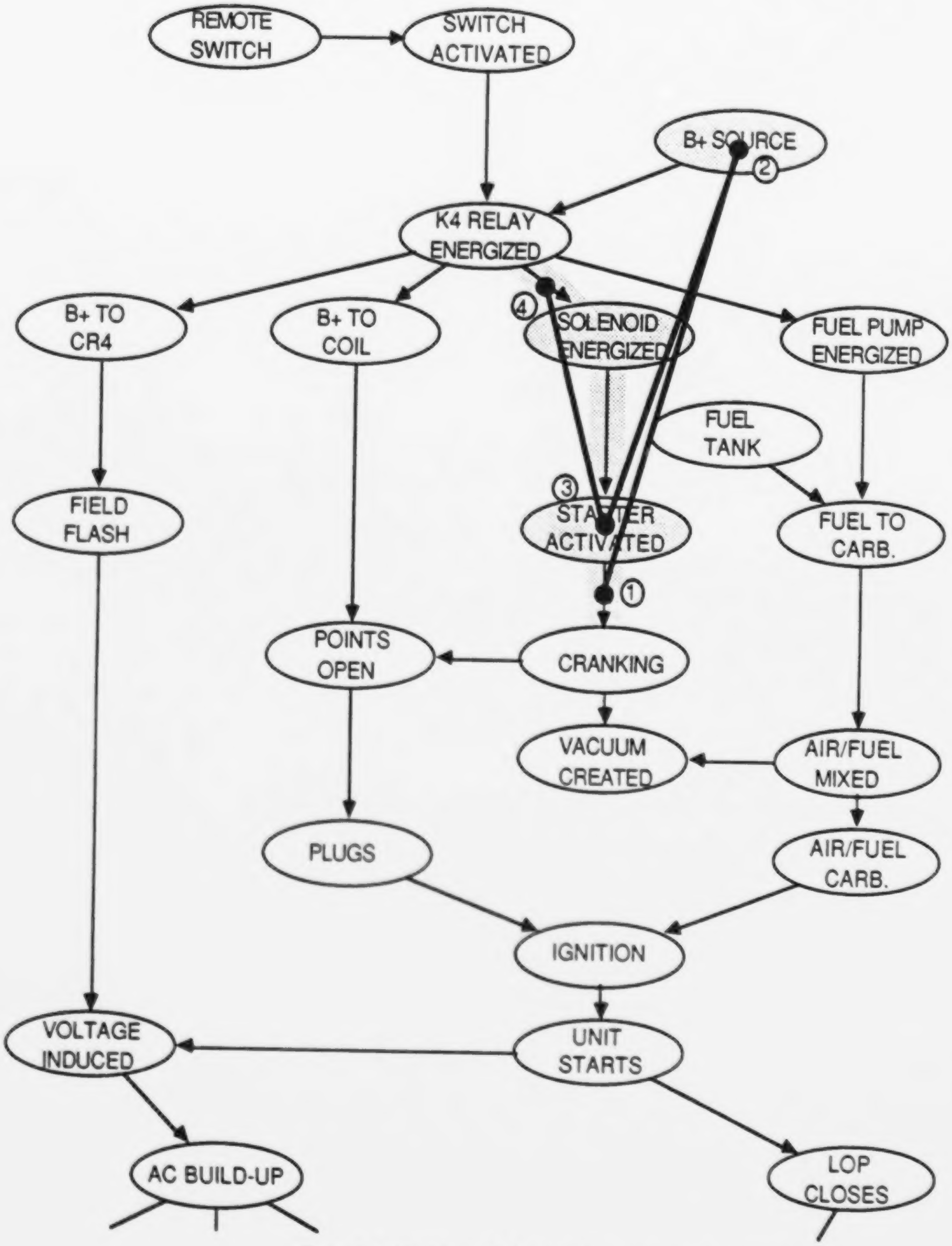
Expert 2 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
K4 RELAY ENERGIZED
⑤
⑥
④
⑦
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
③
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
②
FUEL TO CARB.
①
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

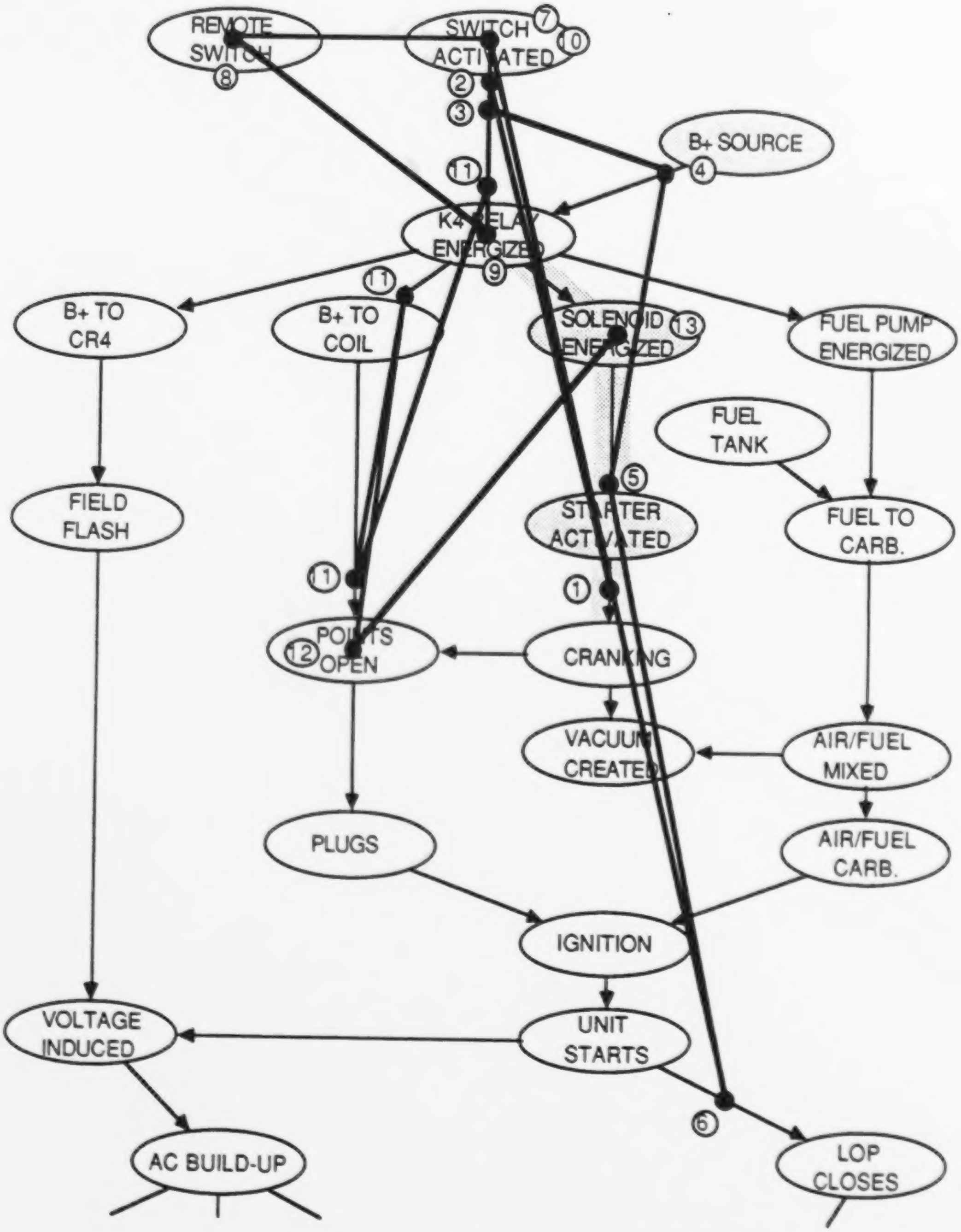
Expert 3 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
②
K4 RELAY ENERGIZED
④
⑤
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
③
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
①
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

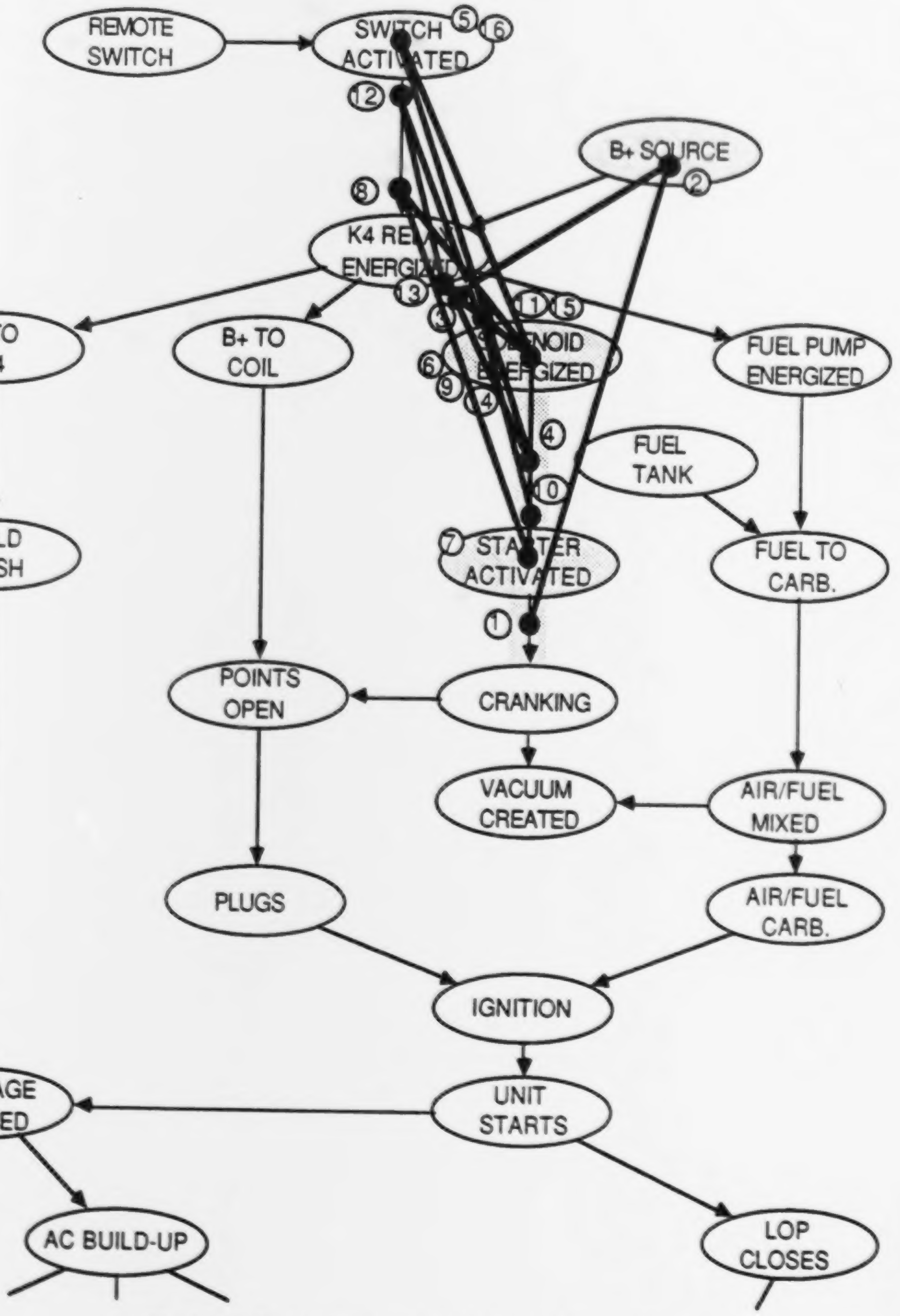
Expert 4 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
SWITCH ACTIVATED
B+ SOURCE
②
K4 RELAY ENERGIZED
④
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
③
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
①
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

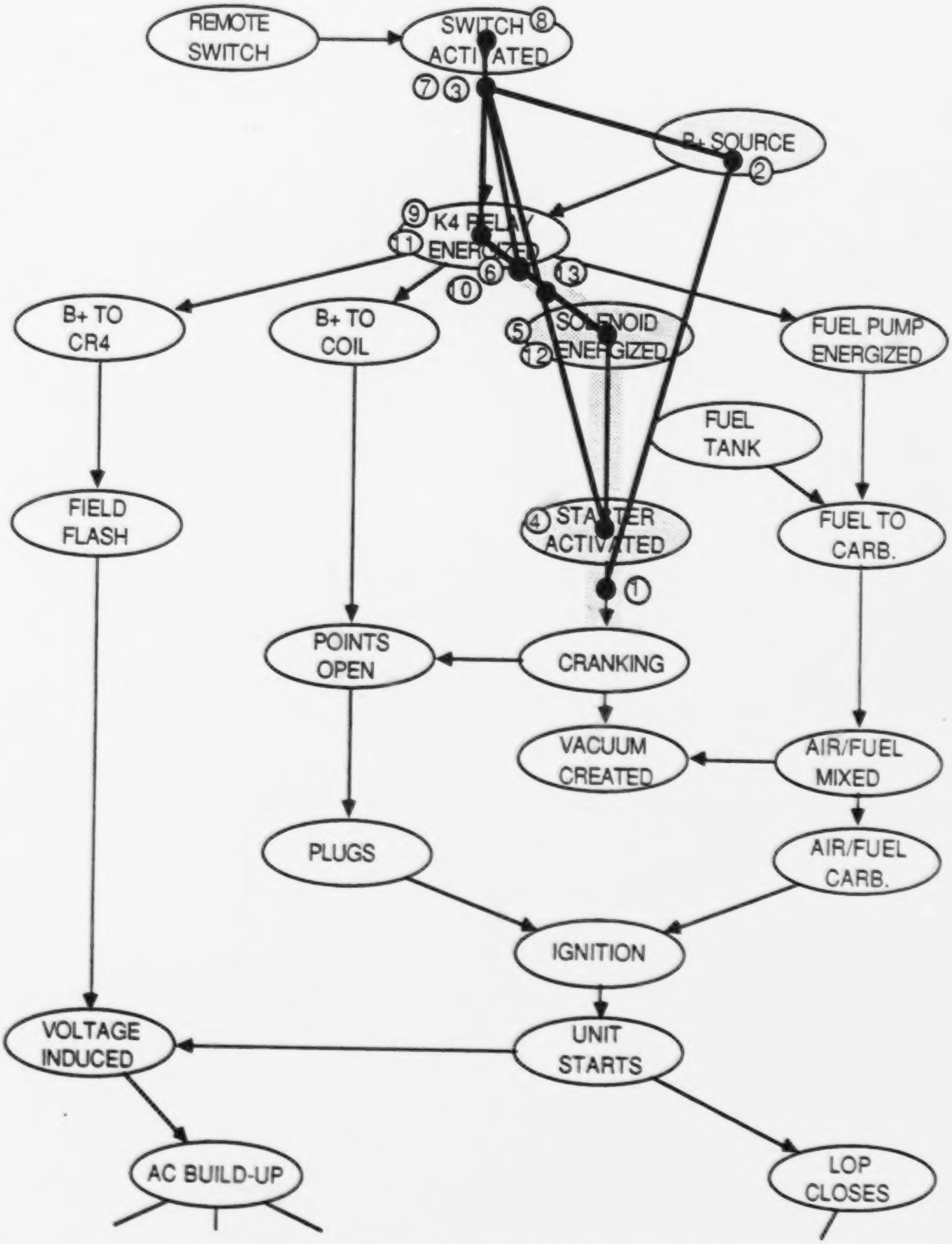
Expert 5 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
⑧
SWITCH ACTIVATED
⑦
⑩
②
③
B+ SOURCE
④
⑪
K4 RELAY ENERGIZED
⑨
⑪
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
⑬
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
⑤
STARTER ACTIVATED
FUEL TO CARB.
⑪
①
POINTS OPEN
⑫
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
⑥
AC BUILD-UP
LOP CLOSES

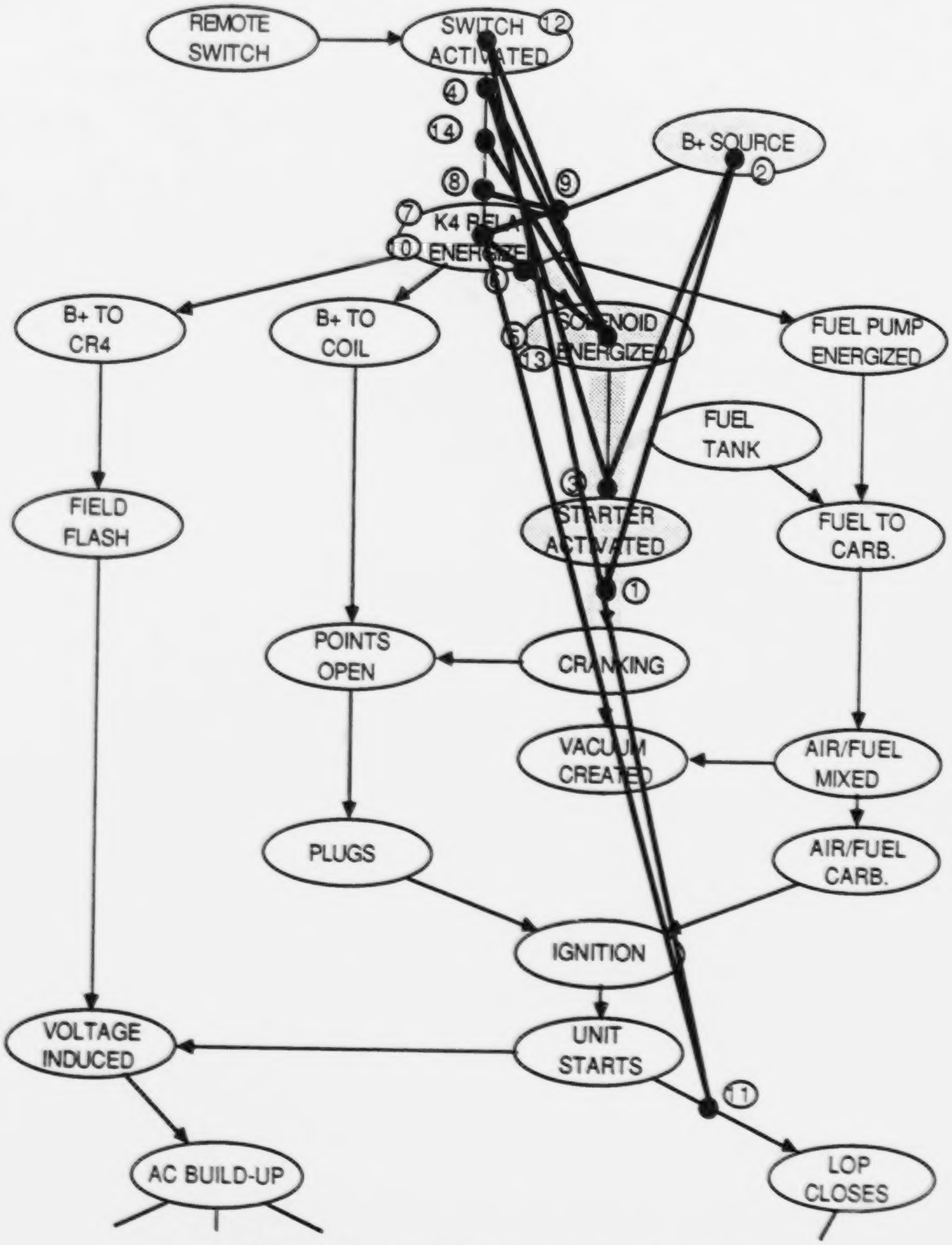
Novice 1 Problem Behavior Map for Wire Problem.
(No solution found.)


REMOTE SWITCH
SWITCH ACTIVATED
5
16
12
B+ SOURCE
2
8
K4 RELAY ENERGIZED
13
11
15
3
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
6
9
14
4
FUEL TANK
10
FIELD FLASH
7
STARTER ACTIVATED
FUEL TO CARB.
1
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

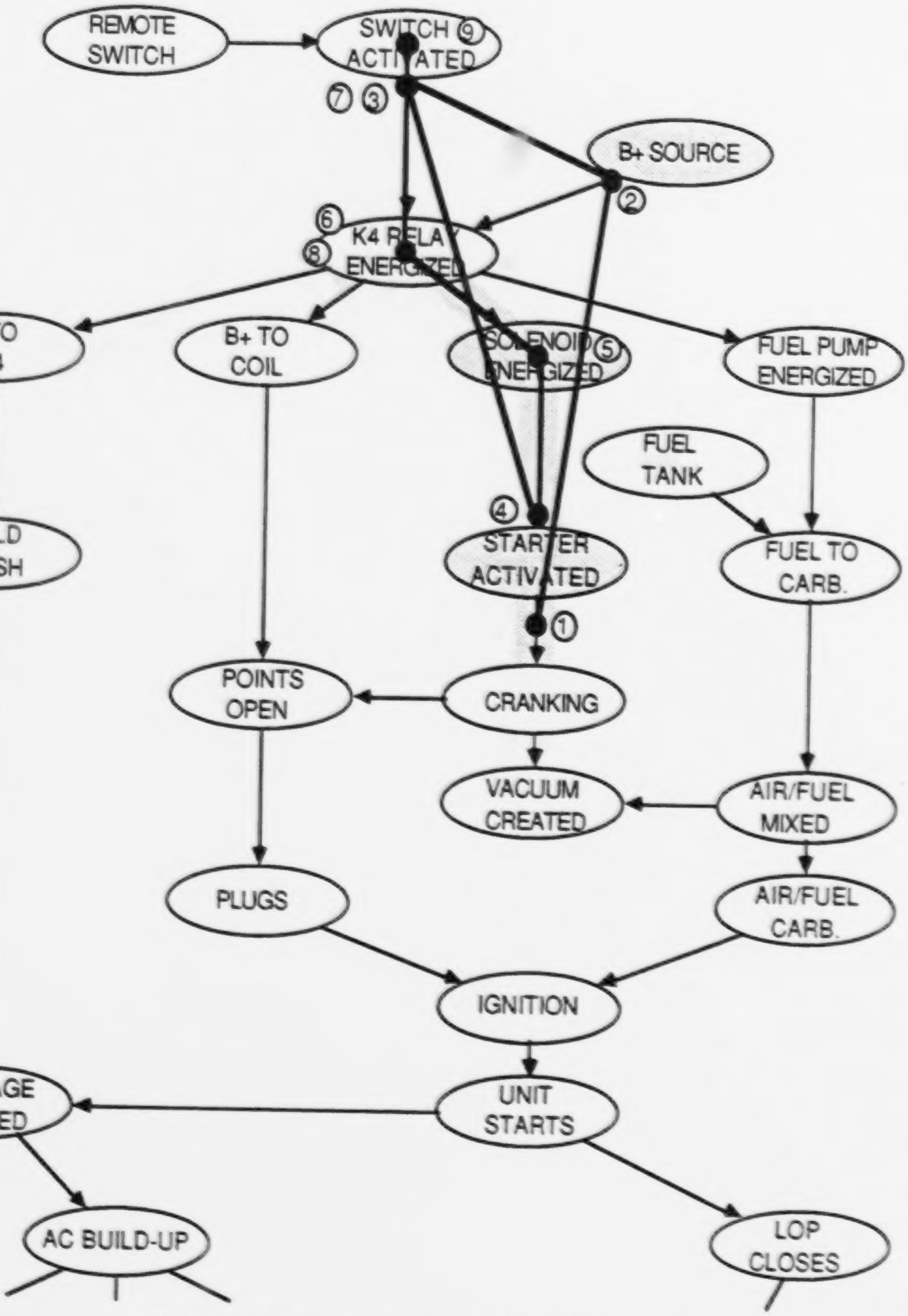
Novice 2 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
SWITCH ACTIVATED
⑧
⑦ ③
B+ SOURCE
②
⑨ K4 RELAY ENERGIZED
⑪
⑩ ⑥
⑬
B+ TO CR4
B+ TO COIL
⑤ SOLENOID ENERGIZED
⑫
FUEL PUMP ENERGIZED
FUEL TANK
FIELD FLASH
④ STARTER ACTIVATED
FUEL TO CARB.
①
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

Novice 3 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
SWITCH ACTIVATED
12
4
14
8
9
B+ SOURCE
2
7
K4 RELAY ENERGIZED
10
6
5
13
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
FUEL PUMP ENERGIZED
FUEL TANK
3
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
1
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
11
AC BUILD-UP
LOP CLOSES

Novice 4 Problem Behavior Map for Wire Problem.


REMOTE SWITCH
SWITCH ACTIVATED
⑨
⑦
③
B+ SOURCE
②
⑥
⑧
K4 RELAY ENERGIZED
B+ TO CR4
B+ TO COIL
SOLENOID ENERGIZED
⑤
FUEL PUMP ENERGIZED
FUEL TANK
④
FIELD FLASH
STARTER ACTIVATED
FUEL TO CARB.
①
POINTS OPEN
CRANKING
VACUUM CREATED
AIR/FUEL MIXED
PLUGS
AIR/FUEL CARB.
IGNITION
VOLTAGE INDUCED
UNIT STARTS
AC BUILD-UP
LOP CLOSES

Novice 5 Problem Behavior Map for Wire Problem.
(No solution found.)